General Comments:
• Closed Book, Closed Notes, and Comprehensive.
• *Equation sheets and Periodic Chart will be included.*
• Mainly numerical, but may include definitions, sketches, qualitative answers, etc.
• Formulas, sketched, and steps to answer must be shown for full credit.
• Appropriate units must be given in all answers.
• Unit conversions and words for acronyms will be provided upon request.
• Partial credit will be given.
• No derivations will be included

The following items are allowed during this examination:
• Calculator

The following items are NOT allowed during this examination:
• Notes, books, and cell phones

Review Items (in order of priority):
• Lecture Notes, Quizzes, Homework Solutions, and Handouts.

Examination Content: (10 Problems of which 8 Problems will be Graded)
• Semiconductor Crystal and Junction Physics (2 problems)
• Diode Circuits (1 problem)
• Bipolar Junction Transistors (2 Problems)
• Field Effect Transistors (2 Problems)
• OpAmp Circuits (2 Problems)
• Photodiodes (1 Problem)

Examination Material:
• Electrical Concepts – current, current density, voltage, electric field, Ohm’s law, insulators, conductors, resistance, resistivity, conductivity, temperature dependence, and associated units.
• Crystals and Carriers – electronic configuration of atoms, valence electrons, use of the periodic table, bonding types, nearest neighbors, band structure for insulators and semiconductors, valence band, conduction band, energy gap, steady-state and equilibrium conditions, elemental and compound semiconductors (Col IV and Col. II-V), intrinsic and extrinsic semiconductors, carrier concentration vs. 1/T, identification of dopants, donors, acceptors, electrons, holes, p-type, and n-type.
• Charge Carriers - calculations of \( n_0 \) and \( p_0 \) for complete impurity ionization, Fermi levels, compensation, drift current in an electric field, resistivity, resistance, conductivity, mobility, variation of mobility with impurity concentration, diffusion current in a concentration gradient, diffusion coefficient, and Einstein relation.
• Junctions and Diodes - contact potential calculations, energy band diagrams, charge density diagrams, calculations for an abrupt junction \((V_o, W, x_{no}, x_{po}, Q_+, \text{ and } Q_-)\) in equilibrium and under bias, low-level injection diode equation, geometry and circuit symbol with voltage and current conventions, graphical load line-diode characteristic solutions of operating point, forward-bias qualitative effects (on diode equation) of high-carrier injection and ohmic losses, reverse-bias effect of breakdown, \(p^n\) and \(n^p\) junctions, and diode circuits.

• Bipolar Junction Transistor – symbol, structure, terminal names, and IV characteristics for both npn and pnp types; energy band diagrams and carrier specifics for equilibrium and typical bias; current relationships including emitter injection efficiency, base transport factor, current transfer ratio, and gain; design optimization for high gain; regions of the IV characteristic; common-base circuit; common-emitter circuit; common-emitter circuit with \(R_e\); Darlington amplifier circuit with 2 transistors; constant current circuit; single biasing source configuration; and emitter follower circuit.

• Junction Field Effect Transistor – symbol, structure, terminal names, and IV characteristics for both n-channel and p-channel JFET types; energy band diagrams and carrier specifics for equilibrium and typical bias; pinch-off voltage and saturation current; design optimization; regions of the IV characteristic; current equations for unsaturated and saturated regions; common-source circuit; source-follower circuit; and self-biasing circuit.

• Metal Oxide Semiconductor Field Effect Transistor – symbol, structure, terminal names, and IV characteristics for both n-channel and p-channel MOSFET types (both depletion-mode and enhancement mode); typical bias conditions; pinch-off or turn-on voltage and saturation current; current equations for unsaturated and saturated regions; and inverter circuit with enhancement-mode and depletion mode MOSFETs.

• Operational Amplifiers – OpAmp model with finite resistances, ideal OpAmp parameters and model, buffer OpAmp circuit, non-inverting OpAmp circuit, inverting OpAmp circuit, multiple input circuits (adders and subtractors), voltage-to-current or current-to-voltage circuits, integrating and differentiating circuits, and multiple stage analysis.

• Optoelectronics – wavelength, frequency, photon energy, phase velocity, refractive index, absorption coefficient, semiconductor absorption, semiconductor emission (injection luminescence), photodiode equation with \(I_{\text{light}}\), photodiode efficiency, photoconductive mode, pin photodiode structure, avalanche photodiode structure (APD), photodiode biasing circuit, LED operation, three requirements for a laser, and laser diode operation.

• Miscellaneous - Semiconductor fabrication (four requirements for a semiconductor device) units of all quantities and \(n_i\) for Si, Ge, and GaAs at RT.
There are 10 problems: please look over the examination to make sure that you have 10 different problems. **Do any eight (8) problems!** Draw a large X through the two problems that you do not want to be graded. If you do not indicate which problems you want to leave out, the first 8 problems will be graded.

Do all work for each problem only on the page supplied for that problem (you may use both sides). **DO NOT** for instance, continue Problem #3 on the back of Problem #2. Extra blank paper will be supplied if needed. If extra paper is used, show the additional work for each problem on a separate sheet and staple the extra sheet(s) to the appropriate problems.
Boltzmann's constant: \( k = 1.381 \times 10^{-23} \text{ J/K} = 8.618 \times 10^{-5} \text{ eV/K} \)
Planck’s constant: \( h = 4.136 \times 10^{-15} \text{ eV-sec} = 6.626 \times 10^{-34} \text{ J-sec} \)
Electronic charge: \( q = 1.602 \times 10^{-19} \text{ C} \)
\( kT \) at 300 K: \( kT = 0.0259 \text{ eV} \)
Free-space permittivity: \( \varepsilon_0 = 8.854 \times 10^{-14} \text{ F/cm} \)
Relative permittivity:
- Si: 11.9
- Ge: 16.0
- GaAs: 13.1
Bandgap energies:
- Si: 1.12 eV
- Ge: 0.67 eV
- GaAs: 1.42 eV
Consider an abrupt pn junction of crystalline silicon (Si). Side #1 has ionized phosphorous (P) dopants only at $N_1 = 10^{16}$ cm$^{-3}$ and side #2 has ionized aluminum (Al) dopants only at $N_2 = 10^{16}$ cm$^{-3}$.

1(a) Identify the junction sides as p-type or n-type. Circle the best choice. (5 pts.)

- Side #1 p-type & Side #2 n-type
- Side #2 p-type & Side #1 n-type
- Insufficient information

1(b) Calculate the contact potential $V_o$ (for equilibrium) (10 pts.)

1(c) Consider the low-level-injection diode equation. Calculate the reverse-bias voltage for which the current magnitude equals 90 percent of the reverse saturation current. The temperature is 300 K. (5 pts.)
For the BJT circuit given let $V_{BB} = 5.0 \text{ V}$, $v_s = 0 \text{ V}$, $R_b = 5.0 \text{ k}\Omega$, $V_{CC} = 15.0 \text{ V}$, and $R_c = 100 \text{ \Omega}$. Assume the base-emitter turn-on voltage is 0.7 V and $\beta = 100$.

2(a) Calculate the base current $i_B$. (5 pts.)

2(b) Calculate the operating point, i.e. the voltage $v_{CE}$ and the collector current $i_C$. (15 pts.)
Consider the OpAmp circuit below with $i_s = 1.0 \sin(10t)$ mA. Let $R_1 = R_2 = 100 \, \Omega$.

3(a) Draw the equivalent circuit in which the OpAmp is replaced with the appropriate circuit elements. Assume ideal input and output resistances ($R_{out}$ and $R_{in}$) and a finite gain $A$. (5 pts.)

3(b) Calculate $v_o$ as a function of $t$ (time). Solve with a finite $A$ and then let $A$ go to infinity. (15 pts.)
The Si p-i-n photodiode shown is reverse-biased for source voltage \( V_S = -100 \) V. The reverse saturation current is 0.050 mA and the quantum efficiency is \( \eta = 0.70 \) for \( \lambda = 900 \) nm. Assume the diode voltage \( |V| >> kT/q \). The diode voltage and diode current are \( V = -50 \) V and \( I = -0.50 \) mA.

4(a) Calculate the optical power absorbed. (10 pts.)

4(b) Calculate the required resistance. (10 pts.)