EE 3329 - Electronic Devices Syllabus

EE 3329 – Electronic Devices Syllabus (“Extended Play”)

The University of Texas at El Paso

The following concepts can be part of the syllabus for the Electronic Devices (EE 3329) course. Note that the list of topics cannot be covered in a semester, it is up to the individual instructors to choose what concepts they wish to cover.

I. Introduction to Quantum Mechanics

* Principles of Quantum Mechanics

- Energy Quanta
- Wave-Particle Duality
- The Uncertainty Principle

* Schrödinger’s Wave Equation

- The Wave Equation
- Physical Meaning of the Wave Function
- Boundary Conditions

* Applications of Schrödinger’s Wave Equation

- Electron in Free Space
- The Infinite Potential Well
- The Step Potential Function
- The Potential Barrier

II. Introduction to the Quantum Theory of Solids

* Allowed and Forbidden Energy Bands

- Formation of Energy Bands
- The Kronig-Penney Model
- The k-Space Diagram

* Electrical Conduction in Solids

- The Energy Band and the Bond Model
- Drift Current
- Electron Effective Mass
- Concept of the Hole

- Metals, Insulators, and Semiconductors

III. Metal-Semiconductor and Semiconductor Heterojunctions

* Heterojunctions

- Heterojunction Materials
- Energy-Band Diagrams
- Two-Dimensional Electron Gas
- Equilibrium Electrostatics
- Current-Voltage Characteristics

IV. Semiconductors: A General Introduction

* General Material Properties

- Composition
- Purity
- Structure

* Crystal Structure

- The Unit Cell Concept
- Simple 3-D Unit Cells
- Semiconductor Lattices
- Miller Indices

* Crystal Growth

- Obtaining Ultrapure Si
- Single-Crystal Formation

* Summary

V. Carrier Modeling

* Semiconductor Models

- Bonding Model
- Energy Band Model
- Carriers
- Band Gap Energy and Material Classification

* Carrier Properties

- Charge
- Effective Mass
- Carrier Numbers in Intrinsic Material
- Manipulation of Carrier Numbers – Doping
- Carrier-Related Terminology

* State and Carrier Distributions

- Density of States
- The Fermi Function
- Equilibrium Distribution of Carriers

* Equilibrium Carrier Concentrations

- Formulas for *n* and *p*
- Alternative Expressions for *n* and *p*
- n_i and *np* Product
- Charge Neutrality Relationship
- Carrier Concentration Calculations
- Determination of E_F
- Carrier Concentration Temperature Dependence

VI. Carrier Action

* Drift

- Definition – Visualization
- Drift Current
- Mobility and Scattering
- Resistivity
- Band Bending

* Diffusion

- Definition – Visualization
- Hot-Point Probe Measurement
- Diffusion and Total Currents
  Diffusion Currents
  Total Currents
- Relating Diffusion Coefficients/Mobilities
  Constancy of the Fermi Leve
  Current Flow Under Equilibrium Conditions
  Einstein Relationship

* Recombination – Generation

- Definition – Visualization
  Band-to-Band Recombination
  R-G Center Recombination
  Auger Recombination
  Generation Process

* Equations of State

- Continuity Equations
- Minority Carrier Diffusion Equations
- Simplifications and Solutions
- Problem Solving
  Sample Problem No. 1
  Sample Problem No. 2

* Supplemental Concepts

- Diffusion Lengths
- Quasi-Fermi Levels

VII. *pn* Junction Electrostatics

* Quantitative Electrostatic Relationships

- Assumptions/Definitions
- Step Junction with $V_A = 0$
  Solution for p
  Solution for E
  Solution for V
  Solution for x_n and x_p
- Step Junction with V_A ? 0
- Examination/Extrapolation of Results
- Linearly Graded Junctions

VIII. *pn* Junction Diode: I-V Characteristics

* The Ideal Diode Equation

- Qualitative Derivation
- Quantitative Solution Strategy
  General Considerations
  Quasineutral Regional Considerations
  Depletion Region Considerations
  Boundary Conditions
  “Game Plan” Summary

* Derivation from the Ideal

- Ideal Theory Versus Experiment
- Reverse-Bias Breakdown
  Avalanching
  Zener Process
- The R-G Current
- V_A -> V_{bi} High-Current Phenomena
  Series Resistance
  High-Level Injection

IX. BJT Fundamentals

* Electrostatics
* Introductory Operational Considerations
* Performance Parameters

- Emitter Efficiency
- Base Transport Factor
- Common Base d.c. Current Gain
- Common Emitter d.c. Current Gain

X. BJT Static Characteristics

* Ideal Transistor analysis

- Solution Strategy
  Basic Assumptions
  Notation
  Diffusion Equations/Boundary Conditions
  Computational Relationships
- General Solution (*W* Arbitrary)
  Emitter/Collector Region Solutions
  Base Region Solution
  Performance Parameters/Terminal Currents
- Simplified Relationships
  ?p_B(x) in the Base
  Performance Parameters
- Ebers – Moll Equations and Model

* Deviations from the Ideal

- Ideal Theory/Experiment Comparison
- Base Width Modulation
- Punch-Through

- Avalanche Multiplication and Breakdown
  Common Base
  Common Emitter
- Geometrical effects
  Emitter Area ? Collector Area
  Series Resistances
  Current Crowding
- Recombination – Generation Current
- Graded Base
- Figure of Merit

XI. MOS Fundamentals

* Ideal Structure Definition
* Electrostatics – Mostly Qualitative

- Visualization Aids
  Energy Band Diagram
  Block Charge Diagrams
- Effect of an Applied Bias
  General Observations
  Specific Biasing Regions

* Electrostatics – Quantitative Formulation

- Semiconductor Electrostatics
  Preparatory Considerations
  Delta-Depletion Solution
- Gate Voltage Relationship

* Capacitance – Voltage Characteristics

- Theory and Analysis
  Qualitative Theory
  Delta – Depletion Analysis
- Computations and Observations
  Exact Computations
  Practical Observations

XII. MOSFETs – The Essentials

* Qualitative Theory of Operation
* Quantitative I_D – V_D Relationships

- Preliminary Considerations

Threshold Voltage
Effective Mobility
- Square-Law Theory
- Bulk-Charge Theory
- Charge-Sheet and Exact-Charge Theories

XIII. Nonideal MOS

* Metal-Semiconductor Workfunction Difference
* Oxide Charges

- General Information
- Mobile Ions
- The Fixed Charge
- Interfacial Traps
- Induced Charges

  Radiation Effects
  Negative-Bias Instability
- ?V_G Summary

* MOSFET Threshold Considerations

- V_T Relationships
- Threshold, Terminology, and Technology
- Threshold Adjustment
- Back Biasing
- Threshold Summary