

## Chapter 1 SEMICONDUCTOR PHYSICS AND DEVICES

### 1.1 Introduction

#### 1.1.1 Conduction in Solids

#### 1.1.2 Conductors, Semiconductors, and Insulator

#### 1.1.3 P-Type and N-Type Semiconductors

##### 1.1.4 Semiconductor Conductivity

### 1.2 Diodes

#### 1.2.1 Diode Structure and Characteristics

#### 1.2.2 PN Diode Structure

#### 1.2.3 Zener Diode Structure

#### 1.2.4 Diode Applications

### 1.3 Bipolar Junction Transistors

#### 1.3.1 Symbol and Physical Structure

#### 1.3.2 BJT Configuration

#### 1.3.3 Second Order Effects

### 1.4 Field Effect Transistors

#### 1.4.1 Junction Field Effect Transistors (JFET)

#### 1.4.2 Metal Oxide Semiconductor Field Effect Transistor (MOSFET)

#### 1.4.3 Advantages of MOSFET over JFET

### 1.5 Emerging Devices beyond MOS

#### 1.5.1 Issues with CMOS Technology Scaling

#### 1.5.2 Emerging Nano-scale Device Technologies

### 1.6 Summary

### 1.7 Multiple Choice Questions

### 1.8 Short Answer Questions

### 1.9 Long Answer Questions

### 1.10 References

## CHAPTER 2 VLSI SCALING AND FABRICATION

### 2.1 Introduction to VLSI Scaling

#### 2.1.1 History and Introduction of VLSI Technology

#### 2.1.2 VLSI Design's Concept

#### 2.1.3 Moore's Law

#### 2.1.4 Scale of Integration

#### 2.1.5 Types of VLSI Chips ( Analog & Digital)

#### 2.1.6 Layout, and Micron & Lambda Rules

### 2.2 VLSI Fabrication Process

#### 2.2.1 Purification, Crystal Growth, and Wafer Processing (CZ and FZ Process)

#### 2.2.2 Oxidation

#### 2.2.3 Epitaxial Deposition

#### 2.2.4 Lithography

#### 2.2.5 Polysilicon and Dielectric Deposition

#### 2.2.6 Diffusion

#### 2.2.7 Ion Implantation

#### 2.2.8 Metallization

#### 2.2.9 Etching Process

### 2.3 Basic CMOS Technology

#### 2.3.1 N-Well and P-Well CMOS Process

#### 2.3.2 Twin Tub Process

- 2.4 Summary
- 2.5 Multiple Choice Questions
- 2.6 Short Answer Questions
- 2.7 Long Answer Questions
- 2.8 References

## CHAPTER 3 MOSFET MODELING

- 3.1 Introduction to MOS Transistor
  - 3.1.1 Characteristics of MOS Transistor
  - 3.1.2 Hot Carrier Effects
  - 3.1.3 Parasitics of MOSFET
  - 3.1.4 MOSFET Circuit Models
- 3.2 MOS Capacitor
  - 3.2.1 MOS Capacitor with Zero and Nonzero Bias
  - 3.2.2 Capacitance-Voltage Curves
  - 3.2.3 Anomalous Capacitance-Voltage Curves
- 3.3 MOSFET DC and Dynamic Models
  - 3.3.1 Pao-Sah Model
  - 3.3.2 Charge Sheet Model
  - 3.3.3 Piece-Wise Model for Enhancement Devices
  - 3.3.4 Small Geometry Model
  - 3.3.5 Intrinsic Charge and Capacitance
  - 3.3.6 Meyer Model
- 3.4 MOSFET Modeling using SPICE
  - 3.4.1 Basic Concepts of Modeling
  - 3.4.2 Model Equations
  - 3.4.3 Examples using HSPICE
- 3.5 Summary
- 3.6 Multiple Choice Questions
- 3.7 Short Answer Questions
- 3.8 Long Answer Questions
- 3.9 References

## CHAPTER 4 COMBINATIONAL AND SEQUENTIAL DESIGN IN CMOS

- 4.1 CMOS Inverter
  - 4.1.1 Design
  - 4.1.2 Operation
  - 4.1.3 Transient and VTC Characteristics
  - 4.1.4 Significance of CMOS Inverter
- 4.2 Static Behavior of Inverter
  - 4.2.1 Switching Threshold
  - 4.2.2 Noise Margin
  - 4.2.3 Robustness of CMOS inverter by scaling supply voltage
- 4.3 Dynamic behavior of CMOS inverter
  - 4.3.1 Capacitances
  - 4.3.2 Power and Energy consumption
- 4.4 Design of Combinational Logic Design
  - 4.4.1 Complementary CMOS logic
  - 4.4.2 Ratioed Logic
  - 4.4.3 Pass-Transistor Logic

- 4.5 CMOS Sequential Design
  - 4.5.1 Introduction
  - 4.5.2 Metrics for CMOS Sequential Design
- 4.6 Static Latches and Registers
  - 4.6.1 The Bistability Principle
  - 4.6.2 SR Flip-Flops
  - 4.6.3 D-latches and Flip-Flops
  - 4.6.4 Master slave Flip-flop
- 4.7 Summary
- 4.8 Multiple Choice Questions
- 4.9 Short Questions
- 4.10 Long Questions
- 4.11 References

## CHAPTER 5 ANALOG CIRCUIT DESIGN

- 5.1 Introduction to Analog Design
- 5.2 MOS device from Analog perspective
  - 5.2.1 I/V Characteristics
  - 5.2.2 Second-order Effects
  - 5.2.3 MOS Small Signal Model
- 5.3 Single Stage Amplifier
  - 5.3.1 Common Source
  - 5.3.2 Common Gate
  - 5.3.3 Source Follower
- 5.4 Current mirrors
  - 5.4.1 Introduction
  - 5.4.2 Basic Current Mirror
  - 5.4.3 Cascode current Mirror
- 5.5 Differential Amplifiers
  - 5.5.1 Single ended and differential Operation
  - 5.5.2 Basic Differential Pair
  - 5.5.3 Differential Pair with MOS load
- 5.6 Operational Amplifiers
  - 5.6.1 Fundamentals and General Op-amp metrics
  - 5.6.2 Two Stage Op-amp
- 5.7 Digital-to-Analog and Analog-to-Digital Converters
  - 5.7.1 Introduction
  - 5.7.2 Types of Digital-to-Analog Converters
  - 5.7.3 Types of Analog-to-Digital Converters
- 5.8 Summary
- 5.9 Multiple Choice Questions
- 5.10 Short Answer Questions
- 5.11 Long Answer Questions
- 5.12 References

## CHAPTER 6: DIGITAL DESIGN THROUGH VERILOG HDL

- 6.1 Introduction
  - 6.1.1 What is Verilog HDL
  - 6.1.2 Background

- 6.1.3 Compiler Directives
- 6.1.4 Data Types
- 6.1.5 Operators
- 6.2 Module and Test bench Definitions
  - 6.2.1 Module
  - 6.2.2 Test bench
- 6.3 Gate-Level Modeling
  - 6.3.1 Built-in primitives
  - 6.3.2 Single and multiple input gates
  - 6.3.3 Tristate gates
  - 6.3.4 MOS Switch
  - 6.3.5 Gate Delays
  - 6.3.6 Example
- 6.4 Dataflow Modeling
  - 6.4.1 Continuous Assignments
  - 6.4.2 Delays
  - 6.4.3 Examples: Verilog Program for Full Adder
- 6.5 Behavioral Modeling
  - 6.5.1 Initial Statement
  - 6.5.2 Always Statement
  - 6.5.3 Procedural Assignments
  - 6.5.4 Conditional Statements
  - 6.5.5 Loop Statements
  - 6.5.6 Examples
- 6.6 Tasks and Functions
  - 6.6.1 Tasks
  - 6.6.2 Functions
- 6.7 Summary
- 6.8 Multiple Choice Questions
- 6.9 Short Questions
- 6.10 Long Questions
- 6.11 References

## CHAPTER 7 VLSI INTERCONNECT AND IMPLEMENTATION

- 7.1 An overview of the VLSI Interconnect Problem
  - 7.1.1 Interconnect Scaling Problem
  - 7.1.2 Implementation of Interconnect Problem
- 7.2 Interconnect Aware Design Methodology and Electrical Modeling
  - 7.2.1 Impact of Scaling
  - 7.2.2 Transistor Scaling
  - 7.2.3 Interconnect Scaling
- 7.3 Electrical Circuit Model of Interconnect
  - 7.3.1 Ideal Interconnect
  - 7.3.2 Resistive Interconnect
  - 7.3.3 Capacitive Interconnect
  - 7.3.4 Resistive Interconnect Tree
- 7.4 Estimation of Interconnect Parasitics
  - 7.4.1 Interconnect Resistance Estimation
  - 7.4.2 Interconnect Inductance Estimation

- 7.4.3 Interconnect Capacitance Estimation
  - 7.4.3.1 Parallel Plate Capacitor
  - 7.4.3.2 Fringing Capacitance
  - 7.4.3.3 Lateral Capacitance
- 7.5 Calculation of Interconnect Delay
  - 7.5.1 RC Delay Model
  - 7.5.2 Elmore Delay Model
  - 7.5.3 Transfer Function Model based on ABCD Parameter matrix
  - 7.5.4 Finite Difference Time Domain Model (FDTD)
- 7.6 Estimation of Interconnect Crosstalk Noise
- 7.7 Estimation of Interconnect Power Dissipation
- 7.8 Summary
- 7.9 Multiple Choice Questions
- 7.10 Short Answer Questions
- 7.11 Long Answer Questions
- 7.12 References

## CHAPTER 8 VLSI DESIGN AND TESTABILITY

- 8.1 Preamble
- 8.2 Basic Digital Troubleshoot
  - 8.2.1 Manufacturing Test
  - 8.2.2 Tester and Test Fixtures
  - 8.2.3 Test Programs
- 8.3 Effect of Physical Faults on Circuit Behavior
  - 8.3.1 Fault Models
    - 8.3.1.1 Line Stuck-at Faults
    - 8.3.1.2 Transistor Stuck-at Faults
    - 8.3.1.3 Floating Line Faults
    - 8.3.1.4 Bridging Faults
- 8.4 Test Principles of Manufacturing
  - 8.4.1 Observability
  - 8.4.2 Controllability
  - 8.4.3 Fault Coverage
  - 8.4.4 Automatic Test Pattern Generation (ATPG)
  - 8.4.5 Delay Fault Testing
- 8.5 Test Approaches
  - 8.5.1 Ad Hoc DFT Techniques
  - 8.5.2 Scan Design Test
  - 8.5.3 Built-in-Self-Test (BIST)
  - 8.5.4 IDDQ Testing
- 8.6 Design for Manufacturability (DFM)
- 8.7 System on Chip (SOC) Testing
- 8.8 Summary
- 8.9 Multiple Choice Questions
- 8.10 Short Answer Questions
- 8.11 Long Questions
- 8.12 References

## CHAPTER 9 NANO-MATERIALS AND APPLICATIONS

- 9.1 Preamble of Nano-Materials

- 9.2 Introduction to Carbon Nanotubes (CNTs)
  - 9.2.1 The concept of Chirality on CNT
  - 9.2.2 Electronic Band Structure
  - 9.2.3 Brillouin zone
- 9.3 Overview of Graphene Nanoribbon (GNR)
- 9.4 Properties of CNT and GNR
- 9.5 Fabrication Approaches for Graphene Nanostructure
  - 9.5.1 The transfer process of graphene on the Si/SiO<sub>2</sub> substrate
  - 9.5.2 CNT Fabrications
- 9.6 Application of Nano-materials
  - 9.6.1 Graphene Nanoribbon Interconnect
  - 9.6.2 Carbon Nanotube based Interconnect
  - 9.6.3 Nano-Sensor
  - 9.6.4 Nanomaterial Based Combat Jacket
  - 9.6.5 Nano Bio-Sensor for Drug Delivery
- 9.7 Summary
- 9.8 Multiple Choice Questions
- 9.9 Short Answer Questions
- 9.10 Long Answer Questions
- 9.11 References

CHAPTER 10 NANOSCALE TRANSISTORS

- 10.1 Issues with CMOS technology scaling
  - 10.1.1 Velocity Saturation and Mobility Degradation
  - 10.1.2 Tunneling Limit
  - 10.1.3 High Field Effects
  - 10.1.4 Power Limitation
  - 10.1.5 Material limitation
- 10.2 Tunnel FET
  - 10.2.1 Device Structure and Models
  - 10.2.2 Device Characteristics
  - 10.2.3 TFET based Circuit design
- 10.3 Negative Capacitance FET
  - 10.3.1 Device Structure
  - 10.3.2 Principle of operation
  - 10.3.3 Low subthreshold swing and high ON current
  - 10.3.4 Hysteresis Characteristics
  - 10.3.5 NCFET device based inverter and digital logic design
- 10.4 Carbon Nanotube FET
  - 10.4.1 Carbon nanotube (CNT)
    - 10.4.2 Carbon nanotube FET (CNTFET)
  - 10.4.2 Device Characteristics
- 10.5 Graphene Nanoribbon FET
  - 10.5.1 Graphene structure and properties
  - 10.5.2 Graphene nanoribbon FET (GNRFET)
- 10.6 Spintronic Devices
  - 10.6.1 Principle of Operation
  - 10.6.2 Spin based Devices
- 10.7 Summary

10.8 Multiple Choice Questions

10.9 Short Answer Questions

10.10 Long Answer Questions

10.11 References