

## Semiconductor Physics

Semiconductors: Energy Band and Charge Carriers: Energy bands in semiconductors, Types of semiconductors, Charge carriers, Intrinsic and extrinsic materials. Carrier concentration: Fermi Level, Electron and hole concentration equilibrium, Temperature dependence of carrier concentration, Compensation and charge neutrality. Conductivity and mobility, Effect of temperature, Doping and high electric field.

Structure, bonding and ionicity of compound semiconductors, binary and ternary alloy systems; phase diagrams - Ga-As, InP, CdTe, and HgCdTe systems; stoichiometry and composition of III-V and II-V compounds, Charge transport, lattice modes and scattering processes, ionized impurity, acoustic, piezoelectric and polar optical scattering, quantum effects - 2 dimensional transport quantum hall effect, super lattices, resonant tunneling, transport in presence of magnetic fields, Gunn effect, impact ionization and avalanche breakdown, Optical absorption and emission, band structure, dependence on temperature, pressure, composition and degeneracy, impurity and free carrier absorption. electrons at heterojunctions, electrons in nanostructures, electrons in coupled nanostructures, photons substrates and epitaxy, thin films, device processing, electronics, in- plane optoelectronics, out-of-plane optoelectronics magneto-optical effects, luminescence, heterojunctions and interfaces, growth and process induced defects, deep levels, persistent photoconductivity, Applications of compound semiconductors as sensors and actuators.

Optical Excitation in Semiconductor: Optical absorption, carrier generation, Carrier life time, diffusion length and photo conductivity, Direct and indirect recombination and trapping, Photoconductive devices. Diffusion of carriers, Einstein relation, Continuity equation, Carrier injection, Diffusion length. Haynes-Shockley experiment.

Junctions: p-n junction and contact potential, Fermi levels, Space charge, Reverse and Forward bias, Zener and Avalanche breakdown. Capacitance of p-n junction, Schottky barriers; Schottky barrier height, C-V characteristics, current flow across Schottky barrier: thermionic emission, Rectifying contact and Ohmic contact.

Field Effect Transistors: JEFT amplifying and switching, Pinch off and saturation, Gate control, I-V characteristics. MOSFET, Operation, MOS capacitor, Debye screening length, Effect of real surfaces; Work function difference, Interface charge, Threshold voltage and its control, MOS C-V analysis and time dependent capacitance. Output and transfer characteristics of MOSFET.

Bipolar Junction Transistors (BJT): Fundamentals of BJT operation. Minority carrier distribution, Solution of diffusion equation in base region, Terminal current, Current transfer ratio, Ebers-Moll equations, Charge control analysis. BJT switching: Cut off, Saturation, Switching cycle.

Photonics: LED: Radiative transition, Emission spectra, Luminous efficiency and LED materials, Solar cell and photodetectors: Ideal conversion efficiency, Fill factor, Equivalent circuit, Voc, Isc and Load resistance, Spectral response. Reverse saturation current in photodetector.

### **Suggested Books:**

*Streetman, B. and Banerjee, S., Solid State Electronics, Prentice Hall India, (2006).*

*Sze, S.M., Physics of Semiconductor Devices, John Wiley, (1981).*

*World of compound semiconductors*

## Semiconductor devices and Technology

Classical scaling in CMOS, Moore's Law, Clean room concept, Material properties, crystal structure, lattice, Growth of single crystal Si, Cleaning and etching, Thermal oxidation, Dopant diffusion in silicon, Deposition & Growth (PVD, CVD, ALD, epitaxy, MBE, ALCVD etc.), Ion-implantation, Lithography (Photolithography, EUV lithography, X-ray lithography, e-beam lithography etc.), Etch (RIE, DRIE, ICP-

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RIE, Wet-Etch) and Cleaning, CMOS Process integration, Back end of line processes (Copper damascene process, Metal interconnects; multi-level metallization schemes), Advanced technologies (SOI MOSFETs, Strained Si, Silicon-Germanium MOS, metal semiconductor source / drain junctions, High K, metal gate electrodes and work function engineering, Double gate MOSFETs, Fin FETs, Tunnel FETs etc.), emerging research devices and architectures (Nanowire FETs, CNT FETs, Graphene transistors, Organic FETs etc.) High Frequency Devices: Essential Condition of High frequency device and compound semiconductor, Fundamentals of MESFET, Concept of Pinch off and threshold voltage, I-V characteristics of MESFET, trans conductance , equivalent circuit and figure of merit of MESFET, Short channel effect , Velocity saturation and velocity overshoot effect of GaAs based MESFET, Evolution of HEMT from MESFET structure, HEMT and triangular potential well, I-V and gate control, Fabrication of MESFET and HEMT structures.

Optical Devices: Fundamentals of compound semiconductor based optical devices, Optical density of States, fundamentals and formation of Heterostructures devices, Fundamentals of LED, essential band structures of LED. Fundamentals of semiconductor LASER with detail theory.

Synthesis of Compound semiconductors, Fabrication of MESFET and HEMT structures, Fabrication of LED and LASER structures.

MEMS devices and Sensor's principle and fabrication technology.

### **Suggested Books:**

1. Stephen Campbell, *The Science and Engineering of Microelectronics*, Oxford University Press, 1996
2. S.M. Sze (Ed), *VLSI Technology*, 2nd Edition, McGraw Hill, 1988
3. *Semiconductor Optoelectronic Devices*, Bhattacharya Pallab, Pearson
4. *Fundamentals of Semiconductor Fabrication*, Gary S. May, Simon M. Sze, Wiley
5. *Fundamentals of Microelectromechanical Systems (MEMS)*, Eun Sok Kim, The McGraw Hill

## **Materials Characterization Techniques**

Introduction: General instrumental parameters, measurement basics.

Spectroscopic methods: UV-visible spectroscopy- Beer's law, Instrumentation, Quantitative analysis; Vibrational spectroscopy- Raman and Infrared, Principles of vibrational spectroscopy, Infrared and Raman activity, Fourier transform infrared spectroscopy, Instrumentation, Raman spectroscopy, Micro Raman, Applications

Electron spectroscopies: X-ray photoelectron spectroscopy (XPS), Ultra-violet photoelectron spectroscopy (UPS), Auger electron spectroscopy (AES), Atomic model and electron configuration, Principles of XPS and AES, Chemical shift, Depth profiling, Instrumentation, Applications

Optical Microscopy: Image formation, Resolution, Aberrations, Imaging modes, Specimen preparation, Confocal microscopy

Electron microscopy: Scanning electron microscopy (SEM), Instrumentation, Electron beam-specimen interaction, Specimen preparation, Energy dispersive spectroscopy (EDS) in electron microscopes; Transmission electron microscopy (TEM) - Basics of TEM, Electron sources, Specimen preparation, Image modes, Image contrast.

Scanning Probe Microscopies: Scanning tunneling microscope (STM) and Atomic Force Microscope (AFM) - Working principles, working modes, Image artifacts

Thermal analysis: Thermo gravimetric analysis (TGA), Differential thermal analysis (DTA), Differential scanning calorimetry (DSC), Dynamic mechanical analysis (DMA), Thermomechanical analysis (TMA) and Dynamic mechanical thermal analysis (DMTA), Basic theory, Instrumentation and applications

Non-destructive testing: Radiography, Ultrasonic, Acoustic emission, Thermography, Holography, Basic principles, Applications in airframe and rocketry

X-ray techniques: X-ray diffraction- Generation and characteristics of x-ray, Lattice planes and Bragg's law, Theory of diffraction, Wide angle XRD; determination of particle size and micro/macro strains.

Electrochemical & Surface characterization techniques: Cyclic voltammetry, Electrochemical Impedance

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spectroscopy, Contact angle measurement, Surface area analysis: Theory , experiment and its applications  
Nanomaterial characterization: using Dynamic Light Scattering, Introduction to particle size  
characterization, Dynamic Light Scattering: Particle size analysis, Zeta potential measurement:  
Instrumentation, basics and principle of analysis, Laser Doppler Electrophoresis: Stability of colloids,  
Elastic and plastic deformation-mechanical properties of materials, Nano indentation load- displacement  
curves, data analysis methods-Hardness testing of thin films and coatings.

### **Suggested Books:**

*H. Bubert, H. Jenett, Surface and Thin Film Analysis: A Compendium of Principles, Instrumentation, and Applications, Wiley-VCH, 2002.*

*S. Zhang, L. Li, A. Kumar, Materials Characterization Techniques, CRC Press, 2008.*

*Waseda, Yoshio, X-ray diffraction crystallography introduction, examples and solved problems, Springer-Verlag 2011*

*Compton G. Richard and Craig E. Banks, Understanding Voltammetry (2nd Edition), World Scientific, 2011.*

*Kock-Yee Law, Hong Zhao, Surface Wetting Characterization, Contact Angle, and Fundamentals Springer 2015.*

## **Analog and Digital VLSI Design**

BASIC MOS DEVICE PHYSICS MOS Device Models- Review of Small Signal MOS Transistor Models-  
basic CMOS circuits-basic gain stage –super MOS transistor –Primitive analog cells - BICMOS  
Technology- fabrication, layout, design rules-Passive IC components: capacitor, resistor, inductor,  
transformer.

### **BASIC ANALOG CIRCUITS AND AMPLIFIERS:**

Current sources and sinks - Current mirrors/amplifiers - Voltage and current references, Comparator,  
Multiplier. AMPLIFIERS- MOS and BJT inverting amplifier - Improving performance of inverting  
amplifier - CMOS and BJT differential amplifiers - Characterization of Op-Amp - The BJT two stage op-  
amp - The CMOS two stage op-amp -Op-amps with output stage, Folded cascode op-amp,  
Transconductance Amplifier- Instrumentation amplifier.

### **NOISE AND FILTERS:**

Noise Spectrum, Sources, Types, Thermal and Flicker noise, Representation in circuits, Noise Bandwidth,  
Noise Figure. Low pass filters - High pass filters – Band Pass filters – Switched capacitor filters - Phase  
Locked Loops.

### **D/A AND A/D CONVERTERS:**

Ideal A/D and D/A converters, Quantization noise, Signed codes, Performance limitations. D/A converter:  
Current scaling, Voltage scaling and Charge scaling D/A converters - Serial D/A converters - Serial A/D  
converters, Parallel - High performance A/D converters.

### **ANALOG VLSI TESTING AND SYSTEMS:**

FAULT modelling and simulation - BIST – Analog VLSI for Vision - System Design Issues - An Integrated  
Image Acquisition, Smoothing and Segmentation Focal Plane Processor.

### **MOS TRANSISTOR PRINCIPLES AND CMOS INVERTER**

MOSFET Transistor Characteristic under Static and Dynamic Conditions, MOS Transistor Secondary  
Effects, CMOS Inverter - Static Characteristic, Dynamic Characteristic, Power, Energy, and Energy Delay  
parameters.

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## COMBINATIONAL LOGIC CIRCUITS

Static CMOS Design – Complementary CMOS, Ratioed Logic, Pass-Transistor Logic. Dynamic CMOS Design – Dynamic Logic: Basic Principles, Speed and Power Dissipation of Dynamic Logic, Issues in Dynamic Design, Cascading Dynamic Gates.

## SEQUENTIAL LOGIC CIRCUITS

Timing metrics for sequential circuits, Static Latches and Registers, Dynamic Latches and Registers, Pipelines, Pulse and sense amplifier-based Registers, Non-Bistable Sequential Circuits.

## ARITHMETIC BUILDING BLOCKS AND MEMORY ARCHITECTURES

Data path circuits, Architectures for Adders, Multipliers, Shifters, Speed and Area Tradeoffs, Array Subsystems: SRAM, DRAM, ROM.

## ARCHITECTURE DESCRIPTION

Introduction, Power distribution, Input/Output, Clock, Hardware Description Languages, Verilog HDL: Behavioral modeling, Structural gate modeling, Switch modeling, Basic constructs, FSM, High-level synthesis.

### **Suggested Books:**

*Behzad Razavi, Design of Analog CMOS Integrated Circuits, McGraw Hill, 2<sup>nd</sup> Edition 2002.*

*Gray, P.R., Hurst, P.J., Lewis, S.H., and Meyer, R.G., Analysis and Design of Analog Integrated Circuits, John Wiley, 5<sup>th</sup> Edition, 2001.*

*Jan M Rabaey, Anantha Chandrakasan, B Nikolic, Digital Integrated Circuits: A Design Perspective, Second Edition, 2003, Prentice Hall of India.*

*Niel H.E. Weste, David Harris, Ayan Banerjee, CMOS VLSI Design- A circuits and Systems Perspective, Third Edition, 2013, Pearson education.*

*Wayne Wolf, Modern VLSI Design, PHI Learning Private Limited, New Delhi, 2011.*

## **Nanoscience and Technology**

General introduction and theory of nanomaterials- History of nanomaterials; Size and shape dependant properties and their uniqueness; Energy at nanoscale - surface characteristics and electrostatic and steric stabilization - Quantum confinement - zero dimensional, one dimensional and two-dimensional nanostructures, metal nanoparticles, semiconductor nanocrystals (Quantum dots)

Synthesis of nanomaterials- Introduction to nanoparticle synthesis – top-down and bottom-up approaches Nucleation and growth of nanoparticles. - physical nanofabrication techniques (PVD, CVD, MBE, self-assembly & lithographic techniques) and wet chemical methods for the synthesis.

Functional nanomaterials- Synthesis, properties and applications of organic, inorganic, hybrid nanomaterials, self-assembled nanostructures, Carbon based nano materials: fullerene, carbon nanotube, graphene, carbon onion, nanodiamond and films; Biomimetic nanomaterials - introduction to biomimetics, mimicking mechanisms in nature, synthesis and applications of bioinspired nanomaterials.

Applications of nanomaterials- Application of nanomaterials in healthcare, coatings, environment, catalysis, agriculture, automotive, sensors, electronics, photonics, energy and aerospace sectors.

### **Suggested Books:**

*Y. Yin, Y. Xia, Encyclopedia of Nanomaterials, Elsevier, 2023.*

*Bharat Bhushan, (Ed.), Handbook of Nanotechnology, Springer, 2016.*

*Carl C. Koch (Ed.), Nanostructured Materials: Processing Properties and Applications, William Andrew Inc., 2007.*

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