SEMICONDUCTOR DEVICE MODELLING

Course Objectives

1. Understand the fundamental physics of semiconductors, carrier transport mechanisms, and generation-recombination processes.
2. Analyze the electrical characteristics and mathematical models of P-N junction diodes and bipolar junction transistors (BJTs).
3. Explain the operation of MOS capacitors and develop MOSFET current-voltage and capacitance-voltage models.
4. Evaluate short-channel effects and understand the operation of advanced semiconductor devices such as FinFETs and HEMTs.
5. Apply numerical simulation techniques and SPICE-based compact modeling for semiconductor device and circuit analysis.

MODULE 1: Basic Semiconductor Physics & Carrier Transport (6 hours)

Energy Band Models: Energy bands, intrinsic/extrinsic semiconductors, and Fermi-Dirac statistics. Carrier Action: Drift and diffusion currents, mobility, Einstein relation, generation-recombination processes, and the continuity equation.

MODULE 2: P-N Junction & Bipolar Models (6 hours)

P-N Junction Diodes: Mathematical derivation of I-V characteristics, breakdown mechanisms, and small-signal/large-signal capacitances. BJT Modeling: Ebers-Moll and Gummel-Poon models, base transit time, Early effect, and high-level injection.

MODULE 3: MOS Capacitors & MOSFET Physics (6 hours)

MOS Characteristics: Energy band diagrams, flat-band voltage, surface potential, and threshold voltage. MOSFET Modeling: Gradual Channel Approximation (GCA), I-V equations in linear and saturation regions, and C-V characteristics (oxide, depletion, and inversion capacitances).

MODULE 4: Advanced & Short-Channel Effects (6 hours)

Scaling Challenges: Velocity saturation, drain-induced barrier lowering (DIBL), channel length modulation, and hot-carrier effects. Advanced Architectures: Introduction to FinFETs, HEMT.

MODULE 5: Device Simulation & Circuit Modeling (6 hours)

Numerical Modeling: Discretization techniques, Drift-Diffusion models, and solving Poisson's equation. SPICE Modeling: Introduction to compact modeling and extracting parameters for circuit simulation.

Course Outcomes (COs)

Upon successful completion of the course, students will be able to:

CO1: Explain semiconductor energy band theory, carrier transport mechanisms, continuity equations, and recombination-generation phenomena.

CO2: Derive and analyze the I-V and C-V characteristics of P-N junction diodes and evaluate BJT models such as Ebers-Moll and Gummel-Poon.

CO3: Model MOS capacitors and MOSFETs, and analyze their electrical behavior under different operating conditions.

CO4: Investigate short-channel effects, scaling limitations, and the characteristics of modern semiconductor devices including FinFETs and HEMTs.

CO5: Utilize numerical methods, drift-diffusion models, Poisson equation solvers, and SPICE compact models for semiconductor device simulation and parameter extraction.

Text Books

1. Semiconductor Devices: Modeling and Technology – Nandita Das Gupta and Amitava Das Gupta, PHI Learning, 2004.
2. Modern Semiconductor Devices for Integrated Circuits – C. C. Hu, Pearson Education, 2010.
3. Physics of Semiconductor Devices – Wiley India, 2007.

Reference Books

1. Fundamentals of Semiconductor Devices – McGraw-Hill Education, 2009.
2. Fundamentals of Semiconductor Devices – McGraw-Hill, 2005.
3. Research articles and technical reports in semiconductor device experimentation, modeling, TCAD simulation, and compact modeling.