Centre for VLSI and Nanotechnology

B.Tech. Minor Nanoelectronics Course Book

Course Name: ENL 202 - Introduction to Nanoelectronics

Prerequisites: Nil

Offered in: Odd Semester (3rd Semester)

Scheme and Credit: [(3-0-0); Credits: 3]

Type of Course: Elective

Course Theory Assessment: Midsem Exam (30%), Internal assessment through Assignments /Seminar /Quizzes (20%), End Semester Exam (50%).

Course Outcomes

Students will

1. Be able to build nanoscale level devices and systems
2. Be familiar with quantum devices, and their applications to circuits.
3. Be able to link knowledge of device physics with nanoelectronics
4. Have the ability to formulate problems, problem solving skills.
5. Be able to analyze optoelectronic devices and its applications.

Relationship of Course Objectives to Program outcomes:

POs → COs ↓	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	3	3	3	3	3	1	2	2	1	1	1
CO2	3	3	2	3	3	-	1	1	-	1	2	2
CO3	3	3	2	2	1	-	1	-	1	1	1	-
CO4	3	3	3	2	1	2	2	-	1	1	1	-
CO5	3	3	3	3	2	3	1	1	2	1	1	1

Content (CO wise)

Basics of Quantum Mechanics: Schrodinger equation, Density of States. Particle in a box Concepts, Degeneracy. Band Theory of Solids. Kronig-Penny Model. Brillouin Zones.

Basic Device Physics: Evolution of Semiconductor devices, carrier concentrations, Excess carriers and recombination processes, Carrier Transport Mechanisms, Fundamental Device Equations.

Overview of Integrated Circuit Fabrication Technologies: Crystal Growth, Epitaxy, Oxidation, Diffusion, Ion Implantation, Metalization, Photolithography and etching.

Introduction to Micro-Electro Mechanical Systems: Smart Materials, Structures and Systems, Integrated Microsystems, Micro/Nano Sensors and actuators, Smart sensors, Micro-actuator systems.

Overview of nanoelectronic devices for electronic circuits: Bulk MOSFETs, Scaling challenges and nanoscale MOSFETs, multi-gate architectures, Tunneling Junctions and supporting devices.

Nanophotonics and its applications: Optoelectronic properties, Introduction to Nanophotonic devices and its applications, Nanophotonic logic gates, Modern optical science and technology.

Text Books

1. G.W. Hanson, Fundamentals of Nanoelectronics, Pearson, 2009.
2. Yuan Taur, Fundamentals of Modern VLSI Devices, Cambridge University Press, 2010

Reference Books

1. G.K. Ananthasuresh, K.J. Vinoy, S. Gopalkrishnan, K.N. Bhat, V.K. Aatre, Micro and Smart Systems, Wiley India, 2010.
2. S. K. Ghandhi, VLSI Fabrication Principles: Silicon and Gallium Arsendie, 2nd Edition, John Wiley and Sons, 1994
3. S. V. Gaponenko , Introduction to Nanophotonics , Cambridge Press, 2009

Course Name: ENL 301 – IC Fabrication Technology

Prerequisites: Nil

Offered in: Even Semester (4th Semester)

Scheme and Credit: [(3-0-2); Credits: 4]

Type of Course: Elective

Course Theory Assessment: Midsem Exam (30%), Internal assessment through Assignments /Seminar /Quizzes (20%), End Semester Exam (50%).

Course Outcomes

Students will

1. Be able to understand the Monolithic IC fabrication technology.
2. Be familiar with the clean room and the guidelines to be followed in the fabrication laboratories.
3. Be able to link knowledge of device fabrication, IC developments and system developments in the semiconductor industry.
4. Have the ability to develop the real time systems.
5. Be able to analyze CMOS fabrication processes.

Relationship of Course Objectives to Program outcomes:

POs → COs ↓	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	3	3	2	3	3	1	2	2	1	1	2
CO2	3	3	2	3	3	-	1	1	-	1	2	2
CO3	3	2	2	2	1	-	1	-	1	2	1	-
CO4	3	3	3	2	1	2	2	-	1	1	1	-
CO5	3	3	3	3	2	3	1	1	2	2	1	1

Content (CO wise)

General overview of current status of Micro and Nano fabrication technologies: Interaction between Technology and Design, Interaction between Physics and Technology, Limits of Technology.

Monolithic Fabrication Techniques: Crystal growth S ource of silicon, Single crystalline and Poly crystalline; Epitaxial Process, Oxidation, Lithography, Etching, Diffusion and Ion Implantation, Metallization

Environment for Integrated Circuits Manufacture: Clean Rooms and Wafer cleaning procedures, Technology details of the Laboratory, Contamination Control.

Processes in Fabrication: Deposition (PVD: Sputtering, Evaporation, MBE, PLD(epitaxy); CVD: PECVD, LCVD, ALD), Etching (Wet, Dry, Powder Blast), Doping (Diffusion, Ion Implantation), Oxidation, Characterization of Processes.

Lithography and Mask generation techniques: Optical, Laser, X-ray, Direct(E-beam), Nanoimprint, Soft, Pattern transfer, LIGA.

Device Fabrication examples: NMOS Technology, Mask sequence based fabrication process for NMOS transistors, Silicon Gate and Metal Gate Technologies, Limitations of NMOS Technology.

Laboratory: Practicals based on the theory.

Text books

1. S. A. Campbell, Fabrication Engineering at the Micro- and Nanoscale, 4th edition, Oxford University Press, 2008.

2. J.D. Plummer, Silicon VLSI technology: Fundamentals, Practice and Modeling, Pearson Education India, 2009.

Reference Books

1. H. H. Gatzen and S. Volker, Micro and Nano Fabrication-Tools and Processes, Springer, 2015.

2. C.Y. Chang, S.M. Sze, ULSI Technology , McGraw-Hill, 1996.

3. Richard C. Jaeger, Introduction to Microelectronic Fabrication: Volume 5 of Modular Series on Solid State Devices, Pearson, 2002.

4. S. K. Ghandhi, VLSI Fabrication Principles: Silicon and Gallium Arsenide, 2nd Edition, John Wiley and Sons, 1994.

Course Name: ENL 302 – Fundamentals of MEMS and NEMS

Prerequisites: Nil

Offered in: Odd Semester (5th Semester)

Scheme and Credit: [(3-0-2); Credits: 4]

Type of Course: Elective

Course Theory Assessment: Midsem Exam (30%), Internal assessment through Assignments /Seminar /Quizzes (20%), End Semester Exam (50%).

Course Outcomes

Students will

1. Be able to develop the MEMS and NEMS Systems.
2. Be able to fabricate the MEMS sensors and actuators.
3. Be able to link knowledge of mechanical and electronics circuit fundamentals.
4. Have the ability to formulate problems in real time smart systems.
5. Be able to analyze thermal, magnetic and RF sensors.

Relationship of Course Objectives to Program outcomes:

POs → COs ↓	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	3	3	3	3	3	1	2	2	1	1	1
CO2	3	2	2	3	3	1	1	1	-	1	2	2
CO3	3	3	2	2	1	-	1	-	1	1	1	-
CO4	3	3	3	2	1	2	2	-	1	1	2	2
CO5	3	3	2	3	2	3	1	2	2	1	1	1

Content (CO wise)

Introduction and Historical Background, Scaling Effects. Micro/Nano Sensors, Sensors characterization and classifications, Actuators and Systems overview: Case studies, Application of MEMS

Review of Basic MEMS/NEMS fabrication modules: MEMS Fabrication Technologies, Oxidation, Deposition Techniques, Lithography(LIGA), thin film deposition, Etching, MEMS Assembling and Packaging

Principles of sensing and actuation, Components: beam, cantilever, microplates, capacitive effects, piezo element; Measurements: strain pressure, flow

Magnetic and RF MEMS: Magnetic materials, Magnetic materials for MEMS, Magneto resistive sensors, MEMS magnetic sensors and actuators, RF MEMS.

Mechanics of solids in MEMS/NEMS: Stresses, Strain, Hookes's law, Poisson effect, Linear Thermal Expansion, Bending; Energy methods.

Micromachining: Surface Micromachining, sacrificial layer processes, Stiction; Bulk Micromachining, Isotropic Etching and Anisotropic Etching, Wafer Bonding.

Laboratory: Practicals based on the theory.

Text Book

1. G. K. Ananthasuresh, K. J. Vinoy, S. Gopalkrishnan, K. N. Bhat, V. K. Aatre, Micro and Smart Systems, Wiley India, 2012.

2. S. E. Lyshevski, Nano-and Micro-Electromechanical systems: Fundamentals of Nano-and Microengineering (Vol. 8). CRC press, (2005).

Reference Books

1. S. D. Senturia, Microsystem Design, Kluwer Academic Publishers, 2001.

2. M. Madou, Fundamentals of Microfabrication, CRC Press, 1997.

3. G. Kovacs, Micromachined Transducers Sourcebook, McGraw-Hill, Boston, 1998.

4. M.H. Bao, Micromechanical Transducers: Pressure sensors, accelerometers, and gyroscopes, Elsevier, New York, 2000.

5. Journals: 1. Journal of Microlectromechanical Systems, IEEE/ASME. 2. IEEE Transactions on Nanotechnology.

Centre for VLSI and Nanotechnology

B.Tech. Minor Nanoelectronics Course Book

Course Name: ENL 403 – Elements of Nanoelectronics

Prerequisites: Nil

Offered in: Even Semester (6^{th} Semester)

Scheme and Credit: [(3-0-2); Credits: 4]

Type of Course: Elective

Course Theory Assessment: Midsem Exam (30%), Internal assessment through Assignments /Seminar /Quizzes (20%), End Semester Exam (50%).

Course Outcomes

Students will

1. Be able to build nanoscale circuits and systems
2. Be able to analyze the quantum effects in day to day applications.
3. Be able to link knowledge of classical physics and the quantum physics
4. Have the ability to formulate problems, problem solving skills.
5. Be able to analyze the nanoelectronic devices and circuits.

Relationship of Course Objectives to Program outcomes:

POs → COs ↓	**PO1**	**PO2**	**PO3**	**PO4**	**PO5**	**PO6**	**PO7**	**PO8**	**PO9**	**PO10**	**PO11**	**PO12**
CO1	3	3	3	3	3	3	1	2	2	1	1	1
CO2	3	3	2	3	3	-	1	1	-	1	2	2
CO3	3	3	2	2	1	-	1	-	1	1	1	-
CO4	3	3	3	2	1	2	2	-	1	1	1	-
CO5	3	3	3	3	2	3	1	1	2	1	1	1

Content (CO wise)

Shrink-down approaches: Introduction, CMOS Scaling, Beyond CMOS, More than Moore, The nanoscale MOSFET, Finfets, Vertical MOSFETs, limits to scaling, system integration limits (interconnect issues etc.),

Basics of Quantum Mechanics: Schrodinger equation, Density of States. Particle in a box Concepts, Degeneracy, Band Theory of Solids. Kronig-Penny Model. Brillouin Zones.

Electron Transport in Nanostructures: Density of states, Classical transport: classical resistance and conductance, Quantum ballistic transport: quantum Resistance and conductance, Transport of spin, spintronic devices and applications

Free and Confined Electrons: Free Electrons, Confined Electrons, finite potential wells, infinite potential wells, Quantum wells, Quantum wires, Quantum dots.

Tunnel Junctions: Tunneling through a potential barrier, Potential energy profiles, Coulomb blockade, Single-Electron Transistor (SET), Resonant Tunneling Diode (RTD), Applications of tunneling junctions.

Introduction to Carbon nanotube electronics, Bandstructure and transport, devices, applications, 2D semiconductors, Graphene, transition metal dichalcogenides, atomistic simulations

Laboratory: Practicals based on the theory.

Text Books

1. G.W. Hanson, Fundamentals of Nanoelectronics, Pearson, 2009.

2. W. Ranier, Nanoelectronics and Information Technology (Advanced Electronic Materials and Novel Devices), Wiley-VCH, 2003.

Reference Books

1. K.E. Drexler, Nanosystems, Wiley, 1992.

2. J.H. Davies, The Physics of Low-Dimensional Semiconductors, Cambridge University Press, 1998.

3. C. P. Poole, F. J. Owens, Introduction to Nanotechnology, Wiley, 2003.