SEMESTER S5

NANOELECTRONICS

Course Code	PEEVT526	CIE Marks	40
Teaching Hours/Week (L: T:P: R)	3:0:0:0	ESE Marks	60
Credits	3	Exam Hours	2 Hrs. 30 Min.
Prerequisites (if any)	None	Course Type	Theory

Course Objectives:

1. To understand the challenges of scaling of devices to Nano-meter scales
2. To design novel transistor devices to reduce the short channel effects and to improve the performance
3. To understand the Nano-scale quantum transport in Nano electronic devices from atom to transistor
4. To apply quantum mechanics in materials and quantum devices

SYLLABUS

Module No.	Syllabus Description	Contact Hours
1	**Introduction to Nano electronics-Review of MOSFETs-** Band diagram-operation-threshold voltage- current-MOSFET parameters. **Challenges going to sub-100 nm MOSFETs-** Technological and physical limits of Nano electronic systems, characteristic lengths **Scaling and short channel effects-**Channel length, Oxide layer thickness, tunneling, power density, non-uniform dopant concentration, threshold voltage scaling, hot electron effects, sub threshold current, velocity saturation, DIBL, channel length modulation. **High-K gate dielectrics-** Effective oxide thickness, Effects of high-K gate dielectrics on MOSFET performance (Text books 1,2,3)	9
2	**Novel MOS Devices and Performance Optimization** **Silicon-on-insulator devices-**-FD SOI, PD SOI	9

	Multiple gate MOSFETs--Double gate MOSFETs, FinFETs, Nanowires-Multi gate MOSFET physics-natural length and short channel effects. **Multi Gate MOSFET performance optimization**: Fins, Fin Width, Fin Height and Fin Pitch, Fin Surface Crystal Orientation, Fins on Bulk Silicon, Nano-wires. Gate Stack, Gate Patterning, Threshold Voltage and Gate Work function requirements, Poly silicon Gate, Metal Gate, Tunable Work function metal gate, Mobility and Strain Engineering, Nitride Stress Liners, Embedded SiGe and SiC Source and Drain, Local Strain from Gate Electrode, Substrate Strain, Strained Silicon on Insulator. (Text books 1,4)	
3	**Quantum Transport** **Atomistic view of electrical Resistance**-Energy level diagram- What makes electrons flow- The quantum of conductance - Potential profile- Coulomb blockade - Towards Ohm's law **Schrodinger equation**- Method of finite differences – Examples (particle in a box only) **Band structure**- 1-D examples- General result with basis- 2-D example **Sub bands**- Quantum wells, wires, dots, graphene and "carbon nanotubes" --Density of states-Minimum resistance of a wire **Ballistic to Diffusive Transport**-Landauer formula, Landauer-Buttiker formula. Ballistic and Diffusive transport – transmission. (Text books 3,5,6. Use MATLAB codes in the text book "Quantum transport atom to transistor" to illustrate the concepts)	**9**
4	**Applications of Quantum mechanics and Quantum devices** **Tunneling and applications of quantum mechanics**- solution of Schrodinger equation: Free space, Potential well, tunneling through a potential barrier. Potential energy profiles for material interfaces, Applications of tunneling. **Hetero junctions** -Modulation-doped hetero junctions- SiGe strained hetero structures- MODFET- Resonant tunnelling-Resonant tunnelling transistor **Single electron devices** –Coulomb blockade in a Nano capacitor, tunnel junctions, Double tunnel junction--Coulomb staircase, Single electron transistor. **Spintronics**-Transport of spin, GMR-TMR,applications, Spin Transistor (Text books 3,6)	**9**

Course Assessment Method
(CIE: 40 marks, ESE: 60 marks)

Continuous Internal Evaluation Marks (CIE):

Attendance	Assignment/ Microproject	Internal Examination-1 (Written)	Internal Examination- 2 (Written)	Total
5	15	10	10	40

End Semester Examination Marks (ESE)

In Part A, all questions need to be answered and in Part B, each student can choose any one full question out of two questions

Part A	Part B	Total
• 2 Questions from each module. • Total of 8 Questions, each carrying 3 marks **(8x3 =24marks)**	• Each question carries 9 marks. • Two questions will be given from each module, out of which 1 question should be answered. • Each question can have a maximum of 3 sub divisions. **(4x9 = 36 marks)**	**60**

Course Outcomes (COs)

At the end of the course students should be able to:

Course Outcome		Bloom's Knowledge Level (KL)
CO1	Describe the challenges of scaling of electron devices to Nano meter scales	**K2**
CO2	Design novel transistor devices to reduce the short channel effects and improve performance	**K3**
CO3	Outline the Nano scale quantum transport in Nano electronic devices from atom to transistor	**K2**
CO4	Apply quantum mechanics in materials and quantum devices	**K3**

Note*: K1- Remember, K2- Understand, K3- Apply, K4- Analyse, K5- Evaluate, K6- Create*

CO-PO Mapping Table (Mapping od Course Outcomes to Program Outcomes)

	PO1	PO2	PO3	PO4	PO5	PO6	PO7	PO8	PO9	PO10	PO11	PO12
CO1	3	3	2									3
CO2	3	3	3									3
CO3	3	3	2									3
CO4	3	3	3									3

Note: *1: Slight (Low), 2: Moderate (Medium), 3: Substantial (High), -: No Correlation*

Text Books

Sl. No	Title of the Book	Name of the Author/s	Name of the Publisher	Edition and Year
1	Fundamentals of Modern VLSI Devices	Yuan Taur, Tak H Ning	Cambridge University Press,	Second edition 2009
2	Nanoelectronics and Nanosystems	Karl Goser· Peter GlÖsekötter· Jan Dienstuhl	Springer-Verlag Berlin Heide1berg	First Edition, 2004
3	Nanotechnology for microelectronics and optoelectronics,	J M Martinez Duart, R J Martin Palma, F Agullo Rueda	Elsevier,	First Edition, 2006
4	FinFETs and Other multigate Transistors	J-P Colinge	Springer	First Edition, 2008
5	Quantum Transport Atom to Transistor	Supriyo Datta	Cambridge University Press	First Edition, 2005
6	Fundamentals of nano electronics,	George W.Hanson,	Pearson Education.	First Edition 2009

Reference Books				
Sl. No	**Title of the Book**	**Name of the Author/s**	**Name of the Publisher**	**Edition and Year**
1	Fundamentals of Carrier Transport	Mark Lundstrom	Cambridge University Press	Second Edition, 2000
2	High Dielectric Constant materials VLSI MOSFET Applications,	H R Huff, D C Gilmer,	Springer	First Edition, 2004
3	Nanoelectronics and nanosystems From Transistors to Molecular and Quantum Devices	Karl Goser· Peter GlÖsekötter· Jan Dienstuhl	Springer	First Edition, 2004
4	NANOSCALE TRANSISTORS Device Physics, Modeling and Simulation	Mark S. Lundstrom, Jing Guo	Springer	First Edition, 2006
5	Fundamentals of Ultra-Thin-Body MOSFETs and FinFETs	Jerry G. Fossum, Vishal P. Trivedi	Cambridge University Press	First Edition, 2013
6	Introduction to Nanotechnology	Charles P Poole jr. Frank J Owens	John Wiley and Sons	First Edition, 2003
7	Introduction to Quantum Mechanics	David J Griffiths, Darrel F schroetter	Cambridge University Press	Third Edition, 2018

Video Links (NPTEL, SWAYAM…)	
Module No.	**Link ID**
1	https://nptel.ac.in/courses/117108047, https://nanohub.org/resources/5328
2	https://nptel.ac.in/courses/117108047
3	https://nptel.ac.in/courses/117107149, https://nanohub.org/resources/8086,, https://nanohub.org/courses/FON1, https://nanohub.org/resources/5306
4	https://nptel.ac.in/courses/117107149, https://nanohub.org/resources/8086