राष्ट्रीय प्रौद्योगिकी संस्थान मिजोरम

NATIONAL INSTITUTE OF TECHNOLOGY MIZORAM

(An Institute of National Importance under Ministry of Education, Govt. of India)

Chaltlang, Aizawl, Mizoram – 796012

Course Structure & Syllabus for Dual Degree with M. Tech in Computational Nanotechnology and Semiconductors

BATCH: 2023-24 onwards

VIDE **BoS** dated **10.03.2023**, **SENATE SNT 21.15** dated **14.03.2023**

सूक्ष्म कणिका एवं संचार अभियांत्रिकी विभाग

Department of Electronics and Communication Engineering

Course Structure & Syllabus for Dual Degree with M.Tech Programme in Computational Nanotechnology and Semiconductors

Classification of Credits Points:

1 Hr Lecture (L) per week	1 Hr Tutorial (T) per week	1 Hr Laboratory (P) per week
1 Credit	1 Credit	0.5 Credit

Semester I				
Course Code	**Course Name**	**Category**	**L-T-P**	**Credit**
ECL 4101	Nanoelectronics Semiconductor Devices	DC	3-0-0	3
CSL 41XX	Machine Learning	DC	3-0-0	3
ECL/CSL/EEL 41XX	Elective I	DE	3-0-0	3
ECL/CSL/EEL 41XX	Elective II	DE	3-0-0	3
ECL/CSL/EEL 41XX	Elective III	DE	3-0-0	3
ECP 4102	Advance Semiconductor Device Modeling Lab	DC	0-0-2	1
CSP 41XX	Machine Learning Lab	DC	0-0-2	1
ECP 4102	Seminar	DC	0-0-2	1
TOTAL CREDITS				**18**

Semester II				
Course Code	**Course Name**	**Category**	**L-T-P**	**Credit**
ECL 4201	Compound Semiconductors	DC	3-0-0	3
CSL 42XX	Cloud Computing	DE	3-0-0	3
ECL/CSL/EEL 42XX	Elective IV	DE	3-0-0	3
ECL/CSL/EEL 42XX	Elective V	DE	3-0-0	3
CSP 42XX	Cloud Computing Lab	DC	0-0-3	1.5
ECP 4201	Semiconductor System Design Lab	DC	0-0-3	1.5
ECP 4202	VLSI Circuit Lab	DC	0-0-2	1
ECP 4203	Term Paper	DC	0-0-4	2
TOTAL CREDITS				**18**

Semester III				
Course Code	**Course Name**	**Category**	**L-T-P**	**Credit**
ECP 4301	Project Phase – I	DC	0-0-16	8
TOTAL CREDITS				**8**

Semester IV				
Course Code	**Course Name**	**Category**	**L-T-P**	**Credit**
ECP 4401	Project Phase – II	DC	0-0-24	12
TOTAL CREDITS				**12**

SEMESTER WISE CREDIT POINT(s)

Semester	Semester I	Semester II	Semester III	Semester IV	TOTAL
Credits	**18**	**18**	**8**	**12**	**56**

ELECTIVES

Sl. No.	Course Code	Course Name
1	ECL 4X03	Nanophotonic Physics of Devices
2	ECL 4X04	Molecular and Organic Electronics
3	ECL 4X05	Microelectronics Fabrication Technology
4	ECL 4X06	Nanoscale Semiconductor FET
5	ECL 4X07	Low Power VLSI Design
6	ECL 4X08	Physics of Microelectronic Transistors and Modeling
7	ECL 4X09	2D Materials and Semiconductor Physics
8	ECL 4X10	MEMS and Microsystems
9	ECL 4X11	Fundamentals of Semiconductor Materials and Systems
10	ECL 4X12	Bio-medical Electronics and Systems
11	ECL 4X13	RF Microelectronic Devices
12	ECL 4X14	Advanced System Design and Control
13	ECL 4X15	Wearable and Printed Electronics
14	ECL 4X16	Semiconductor Optoelectronics: Theory and Design
15	CSL 4XXX	Artificial Intelligence
16	CSL 4XXX	Advanced Data Structures and Algorithm
17	CSL 4XXX	Neural Networking and Signal Processing
18	CSL 4XXX	Humanoid Interactions and Nanorobotics
19	CSL 4XXX	Bioinformatics
20	EEL 4XXX	Renewable Energy Sources and Systems
21	CSL 4XXX	Optimization techniques

SYLLABUS OF FIRST SEMESTER

ECL 4101 **Nanoelectronics Semiconductor Devices**

L-T-P: 3-0-0 **Credits: 3**

1.	**Introduction:** Nanotechnology and Nanoelectronics, Moore's Law, Review of Semiconductor Electronics, Maxwell's Equation, Poisson Equation, Continuity Equations, carrier concentration, Carrier Transport, Drift, diffusion, density of states, basics of molecular electronics.	**6 Lectures**
2.	**Basics of Quantum Mechanics:** Photoelectric effect, wave nature of particles and wave-particle duality, Compton Effect, Uncertainty Principle, Schrodinger's equations and its applications, wave function and its duality and postulates. Infinite well, finite well, triangular well, potential barrier, tunnelling probability, step-potential function. Atomic orbital, Pauli-exclusion principle, optical device principle, Quantum dots, wires, and wells, Ballistic Transport.	**14 Lectures**
3.	**Nano-Semiconductor Devices:** Overview of MOS and MOSFET, CMOS Scaling and shrink down approaches, Nano MOSFET, Interconnects, FINFET, Tunelling FET, Vertical FET, Junctionless Transistor, Single electron transistors and spintronics.	**14 Lectures**
4.	**Emerging Nano-devices:** SOI MOSFET and FinFET; strained Si FET; Heterostructure on Insulator System; HOI MOSFET, DGFET, FinFET, NanoFET; CGAA, triangular GAA, rectangular GAA, strained channel GAA; strained channel array FinFET and GAA.	**8 Lectures**

Text Books:

1. Solid State Physics, Ashcroft amd Mermin, Thomson Press (India) Ltd, 2003
2. C. Kittel, Introduction to Solid State Physics, Wiley, New York, 1976.
3. Sze, S. M., Lee, M. K., Dhar, R. S., and Nair, A. R., "Semiconductor Physics and Devices and Indian Adaptation", 3rd Ed., Wiley. 2021.

Reference Books:

1. Physics of Optoelectronics Devices, Shun Lien Chuang, Wiley 1995.
2. The Physics of Low-Dimensional Semiconductors, John H. Davies, Cambridge University Press, 1998.

CSL 41XX	**Machine Learning**	
L-T-P: 3-0-0		**Credits: 3**
As per syllabus prescribed by Dept. of Computer Science and Engineering of CSL 1702		

ECL/CSL/EEL 41XX	**Elective I**	
L-T-P: 3-0-0		**Credits: 3**
As per syllabus of the subject chosen from the list of electives.		

ECL/CSL/EEL 41XX	**Elective II**	
L-T-P: 3-0-0		**Credits: 3**
As per syllabus of the subject chosen from the list of electives.		

ECL/CSL/EEL 41XX	**Elective III**	
L-T-P: 3-0-0		**Credits: 3**
As per syllabus of the subject chosen from the list of electives.		

ECP 4101	**Advance Semiconductor Device Modeling Lab**	
L-T-P: 0-0-2		**Credits: 1**
As per syllabus of ECL 2101.		

CSP 41XX	**Machine Learning Lab**	
L-T-P: 0-0-2		**Credits: 1**
As per syllabus of CSL 21XX: Machine Learning.		

ECP 4102	**Seminar**	
L-T-P: 0-0-2		**Credits: 1**
As per topics allotted by the department.		

SYLLABUS OF SECOND SEMESTER

ECL 4201 **Compound Semiconductors**

L-T-P: 3-0-0 **Credits: 3**

1. **Introduction:** Basics of Quantum Mechanics, Expectation Value, Density of states. Electron and Phonons in Cryatals, Heterostructure, Quantum Well and Low dimensional system, Tunnelling Transport, Schrödinger Equation in Electric and Magnetic field, Scattering, 2DEG. **4 Lectures**

2. **Material properties:** Merits of III–V binary and ternary compound semiconductors (GaAs, InP, InGaAs, AlGaAs, SiC, GaN etc.), different SiC structures, SiGe and SiC for high speed devices compared to Si based devices, dopants and electrical properties such as carrier mobility, velocity versus electric field characteristics of these materials, electric field characteristics of materials and device processing techniques, Band diagrams, homo and hetro junctions, electrostatic calculations, Band gap engineering, doping, Material and device process technique with these III-V and IV – IV semiconductors. **16 Lectures**

3. **Metal semiconductor contacts and Metal Insulator Semiconductor and MOS devices:** Native oxides of Compound semiconductors for MOS devices and interface state density. Metal semiconductor contacts, Schottky barrier diode, MESFETs: Pinch off voltage and threshold voltage of MESFETs. D.C. characteristics and analysis of drain current. Velocity overshoot effects and related advantages of GaAs, InP and GaN based devices for high-speed operation. Sub threshold characteristics, short channel effects and performance of scaled down devices. **9 Lectures**

4. **High Electron Mobility Transistors (HEMT):** Hetero-junction devices. Modulation Doped FET(MODFET) for high electron mobility realization. Principle of operation and unique features of HEMT, InGaAs/InP HEMT, Pseudomorphic and Metamorphic HEMT, Hetero junction Bipolar transistors (HBTs): Principle of operation for high-speed applications. GaAs and InP HBT device and surface passivation for stable high gain high frequency performance. SiGe HBTs and concept of strained layer devices; High Frequency resonant –tunneling devices, Resonant-tunneling hot electron transistors **13 Lectures**

Text Books:

1. C.Y. Chang, F. Kai, GaAs High-Speed Devices: Physics, Technology and Circuit Applications, Wiley & Sons.
2. Gandhi S K, VLSI Fabrication Principles: Silicon and Gallium Arsenide, John Wiley & Sons (2013).
3. Sandip Tiwari, Compound Semiconductor Device Physics, Academic Press (1991), ISBN 0- 12-691740-X.
4. S.M. Sze, High Speed Semiconductor Devices, Wiley (1990) ISBN 0-471-62307-5
5. Griffiths, David J. Introduction to Quantum Mechanics. Pearson Prentice Hall, 2004. ISBN: 9780131118928.

Reference Books:

1. David K. Ferry, Ed., Gallium Arsenide Technology, Howard W. Sams & Co., 1985
2. Avishay Katz, Indium Phosphide and Related materials: Processing, Technology and Devices, Artech House, 1992.
3. Ralph E. Williams, Modern GaAs Processing Methods, Artech (1990), ISBN 0-89006-343-5.

CSL 42XX	**Cloud Computing**	
L-T-P: 3-0-0		**Credits: 3**
As per syllabus prescribed by Dept. of Computer Science and Engineering of CSL 2203		

ECL/CSL/EEL 42XX	**Elective IV**	
L-T-P: 3-0-0		**Credits: 3**
As per syllabus of the subject chosen from the list of electives.		

ECL/CSL/EEL 42XX	**Elective V**	
L-T-P: 3-0-0		**Credits: 3**
As per syllabus of the subject chosen from the list of electives.		

CSP 42XX	**Cloud Computing Lab**	
L-T-P: 0-0-3		**Credits: 1.5**
As per syllabus of CSL 21XX: Cloud Computing.		

ECP 4201	**Semiconductor System Design Lab**	
L-T-P: 0-0-3		**Credits: 1.5**
As per syllabus prescribed by the Department.		

ECP 4202	**VLSI Circuit Lab**	
L-T-P: 0-0-2		**Credits: 1**
As per syllabus prescribed by the Department.		

ECP 4203	**Term Paper**	
L-T-P: 0-0-4		**Credits: 2**
As per topics allotted by the Department.		

SYLLABUS OF THIRD SEMESTER

ECP 4301	**Project Phase – I**	
L-T-P: 0-0-16		**Credits: 8**

SYLLABUS OF FOURTH SEMESTER

ECP 4401	**Project Phase – II**	
L-T-P: 0-0-24		**Credits: 12**

ELECTIVES

ECL 4X03 **Nanophotonic Physics and Devices**

L-T-P: 3-0-0 **Credits: 3**

1.	**Fundamentals of Quantum Theory:** Schrodinger's Equation, Square well, Harmonic Oscillator, Hydrogen Atom (3D and 2 0 Exciton Bound and Continuum States), Time-Independent Perturbation Theory, Lowdin's Renormalization Method, Time-Dependent Perturbation Theory.	**7 Lectures**
2.	**Theory of Electronic Band Structures:** Bloch Theorem and K.p method, Kane's model for band structure, k.p method spin orbit, Kronig-Penney Model for a Superlattice, Band Structures of Semiconductor Quantum Wells.	**8 Lectures**
3.	**Electromagnetics and Waveguides:** Maxwell equations, Coulomb gauge, Lorentz gauge, duality principle; Plane wave reflection from a layered media; Propagation matrix approach; Optical Waveguide Theory; Symmetric and Asymmetric Dielectric slab waveguides; Wave guidance in a lossy or gain medium.	**12 Lectures**
4.	**Semiconductor Lasers:** Optical Transitions Using Fermi's Golden Rule, Spontaneous and Stimulated Emissions, Double Hcterojunction Lasers, Quantum-Well Lasers, gain Gain-guided and index guided lasers.	**10 Lectures**
5.	**THz Quantum Cascade Lasers:** Introduction to QCL, Density Matrix Modeling, Experimental results, New active region design, Intra-cavity THz generation, THz imaging lasers, Inter-cavity and voltage distribution study.	**5 Lectures**

Text Books:

1. Solid State Physics, Ashcroft amd Mermin, Thomson Press (India) Ltd, 2003
2. Physics of Optoelectronics Devices, Shun Lien Chuang, Wiley 1995.

Reference Books:

1. Sze, S. M., Lee, M. K., Dhar, R. S., and Nair, A. R., "Semiconductor Physics and Devices and Indian Adaptation", 3rd Ed., Wiley. 2021.
2. The Physics of Low-Dimensional Semiconductors, John H. Davies, Cambridge University Press, 1998.
3. C. Kittel, Introduction to solid state physics, Wiley, New York, 1976.

ECL 4X04 **Molecular and Organic Electronics**
L-T-P: 3-0-0 **Credits: 3**

1. **Introduction to Molecular Electronics:** Need of molecular electronics and atoms-up approach; Strategies of electronic development; Molecular bonding and hybridization; Molecules as electronic devices; Carbon molecules & electronics; Pentacene; Transport in molecular electronics; Graphene devices. **10 Lectures**

2. **Organic and Inorganic Materials & Charge Transport:** Introduction; Organic Materials: Conducting Polymers and Small Molecules, Organic Semiconductors: p-type, n-type, Ambipolar Semiconductors, Charge Transport in Organic Semiconductors, Charge Transport Models, Energy Band Diagram, Organic and inorganic materials for: Source, Drain and Gate electrodes, Insulators, Substrates; Comparison between Organic and Inorganic Semiconductors. **10 Lectures**

3. **Device Physics and Structures:** Organic Thin Film Transistors: Overview of Organic Field Effect Transistor (OFET); Operating Principle; Classification of Various Structures of OFETs; Output and Transfer Characteristics; OFETs Performance Parameters: Impact of Structural Parameters on OFET; Extraction of Various Performance Parameters, Advantages, Disadvantages and Limitations; Carbon nanotube electronics; CNT FET. **12 Lectures**

4. **OLEDs and Organic Solar Cells:** Organic Light Emitting Diodes (OLEDs): Introduction; Different Organic Materials for OLEDs; Classification of OLEDs, Output and Transfer Characteristics; Various Optical, Electrical and Thermal properties, Advantages, Disadvantages and Limitations. Organic Solar Cells: Introduction, Materials, various properties, Characteristics, Advantages, Disadvantages and Limitations and Applications. **10 Lectures**

Text Books:

1. Hagen Klauk, *Organic Electronics: Materials, Manufacturing and Applications,* Wiley-VCH Verlag Gmbh & Co. KGaA, Germany. 2006.
2. Klaus Mullen, Ullrich Scherf, *Organic Light Emitting Devices*: *Synthesis, Properties and Applications*, Wiley-VCH Verlag Gmbh & Co. KGaA, Germany. 2005.

Reference Books:

1. Hagen Klauk, *Organic Electronics II: More Materials and Applications*, Wiley-VCH Verlag Gmbh & Co. KGaA, Weinheim, Germany, 2012.
2. Flora Li, Arokia Nathan, Yiliang Wu, Beng S. Ong, Organic Thin Film Transistor Integration: A Hybrid Approach, Wiley-VCH, Germany; 1st Ed. 2011.
3. Wolfgang Brutting, *Physics of Organic Semiconductors*, WileyVCH Verlag Gmbh & Co. KGaA, Germany. 2005.

ECL 4X05 Microelectronics Fabrication Technology
L-T-P: 3-0-0 Credits: 6

1.	**Introduction:** Integrated Circuits and Planar Process, IC Families, CMOS Process Flow	**2 Lectures**
2.	**Crystal Growth and Wafer Fabrication:** Crystal Structure, Defects in Crystals, Raw materials and Purification, Czochralski and Float-Zone Crystal Growth Methods, Wafer Preparation and Specification, Measurement Methods.	**5 Lectures**
3.	**Lithography:** Light Sources, Wafer Exposure Systems, Photoresists, Mask Engineering, Measurement of Mask Features and Defects, Resist Patterns and Etched Features.	**4 Lectures**
4.	**Oxidation:** Basic Concepts, Wet and Dry methods, Measurement Methods: Physical, Electrical and Optical, Models and Simulation: Linear and Parabolic, Growth Kinetics, Effect of Temperature, Pressure and Crystal Orientation.	**5 Lectures**
5.	**Diffusion:** Dopant Solid Solubility, Fick's Law, Predeposition and drive-in, Gaussian Solution near a Surface, Measurement Methods: SIMS, Spreading Resistance, Sheet Resistance, Capacitance Voltage.	**5 Lectures**
6.	**Ion Implantation:** Role of Crystal Structure, High-Energy Implants, Ultralow Energy Implants, Ion Beam Heating, Measurement Methods, Models: Nuclear Stopping, Electronic Stopping, Damage and annealing.	**5 Lectures**
7.	**Deposition:** Manufacturing Methods, CVD, APCVD, LPCVD, PECVD, PVD, Epitaxial Silicon, MBE, MOCVD, Polycrystalline Silicon, dielectrics and metals, Measurement and models.	**7 Lectures**
8.	**Etching:** Wet, Plasma Etching, Etching of Various Films, Measurement and Models.	**4 Lectures**
9.	**Back-end technology:** Contacts, Interconnects and Vias, Silicide Gates and Source/Drain Regions, IMD Deposition and Planarization, Chemical-Mechanical Polishing, Electro-migration, Measurement methods and methods.	**4 Lectures**

Text Books:

1. Silicon VLSI Technology by James Plummer, M. Deal and P.Griffin, Prentice Hall Electronics and VLSI series, 2009.
2. Semiconductor Devices: Basic Principles, Wiley Student edition, Paperback, 2007, Jasprit Singh
3. VLSI Technology, by S M Sze, McGraw-Hill, 1988.

Reference Books:

1. The Science and Engineering of Microelectronics, by Stephen Campbell, Oxford University Press, 1996.
2. VLSI Fabrication Principles by Sorab K Ghandhi, John Wiley and Sons, 2nd Edition, 1994.
3. Microchip Fabrication by Peter van Zant, MicraGraw Hill, Sixth edition, 2013

ECL 4X06 **Nanoscale Semiconductor FET**
L-T-P: 3-0-0 **Credits: 3**

1. **Fundamental Concepts:** Density of states, 3D, 2D, 1D; carrier densities; ballistic transport: quantum, semi-classical; band-to-band tunneling; MOSFET and Moore's law, Koomey's law; short channel and narrow width effects; Natori's theory, degenerate, nondegenerate and general condition statistics, quantum capacitance. **8 Lecture**

2. **SOI Nano MOSFET:** Short channel effects; Single gate, double gate, triple gate and surround gate (GAA) structures; classical and quantum physical effects in multi-gate SOI MOSFET; Multigate FET technology: active areas of Fin, mobility and strain engineering. **10 Lecture**

3. **Multigate Nano FET Physics:** Double gate MOS system; impact of carrier confinement and quasi-ballistic transport; oxide thickness, and electron tunnelling; Mobility: phonon limited, interface scattering, Coulomb scattering, temperature dependence, strained double gate SOI. **10 Lecture**

4. **Nanowire FET:** Silicon nanowire FET, IV characteristics; electron transport, surface roughness; Bandstructure of carbon nanotubes: graphene, nanotubes, Fermi points; Carbon nanotube FETs. **8 Lecture**

5. **Strain Engineering Nano FET:** Strain engineered hetero-FET; Engineered substrates: virtual substrate, strained SOI; Substrate-induced Strained-Si; Double and tri-layered strain HOI system, Strain effect and thickness calculation, threshold voltage, Mobility, thickness and temperature dependence; Characterization of Strained-Si Hetero-FETs. **6 Lecture**

Text Books:

1. M. Lundstrom, and J. Guo, Nanoscale Transport: Device Physics, Modelling and Simulation, Springer, 2005.
2. Sze, S. M., Lee, M. K., Dhar, R. S., and Nair, A. R., "Semiconductor Physics and Devices and Indian Adaptation", 3rd Ed., Wiley. 2021.
3. J. P. Colinge, FinFETs and Other Multi-Gate Transistors, Springer, 2009.

Reference Books:

1. Y. Taur and T. Ning, Fundamentals of Modern VLSI Devices, Cambridge University Press, 1998.
2. M. C. Petty, Molecular Electronics: From Principles to Practice, Wiley, 2007.
3. G. W. Hanson, Fundamentals of Nanoelectronics, Pearson, 2009.
4. K. Sienicki, Molecular Electronics and Molecular Electronic Devices, CRC Press, 1994.
5. B. P. Wong, A. Mittal, Y. Cao and G. Starr, Nano-CMOS Circuit and Physical Design, Wiley, 2004.
6. B. G. Streetman and S. Banerjee, Solid State Electronic Devices, Pearson, 2008.

ECL 4X07 **Low Power VLSI Design**

L-T-P: 3-0-0 **Credits:3**

1.	**Introduction:** Low power and its applications; Algorithmic, Architectural, Gate and Physical Level power reduction approaches.	**6 Lectures**
2.	**Sources of Power Dissipation:** Dynamic Power Dissipation: Short Circuit Power, Switching Power, Glitching Power; Static Power Dissipation, Degrees of Freedom.	**8 Lectures**
3.	**Supply Voltage Scaling Approaches:** Device feature size scaling, Multi-Vdd Circuits, Voltage scaling using high-level transformations, Dynamic voltage scaling, Power Management.	**8 Lectures**
4.	**Switched Capacitance Minimization Approaches:** Hardware Software Tradeoff, Bus Encoding Two's complement verses Sign Magnitude, Clock Gating.	**8 Lectures**
5.	**Leakage Power minimization Approaches:** Variable-threshold-voltage CMOS (VTCMOS) approach, Multi-threshold-voltage CMOS (MTCMOS) approach, Power gating, Transistor stacking, Dual-Vt assignment approach (DTCMOS).	**8 Lectures**
6.	**Low Power Design Examples:** Memory, Arithmetic circuits.	**4 Lectures**

Text Books:

1. Low Power VLSI CMOS Circuit Design, by A. Bellamour, and M. I. Elmasry, Springer Science + Business Media, 2012.
2. Low Power Design Essentials (Integrated Circuits and Systems), by Jan Rabaey, Springer, 2009.

Reference Books:

1. Principles of CMOS VLSI Design, by Neil H. E. Weste and K. Eshraghian, Addison Wesley (Indian reprint).
2. CMOS Digital Integrated Circuits, by Sung Mo Kang, Yusuf Leblebici,Tata McGraw Hill.
3. Low Power Digital CMOS Design, by Anantha P. Chandrakasan and Robert W. Brodersen, Kluwer Academic Publishers, 1995.
4. Low Power CMOS VLSI circuit design by Kaushik Roy, Sharat C. Prasad, John Willy & Sons, 2009.

ECL 4X08 Physics of Microelectronic Transistors and Modeling
L-T-P: 3-0-0 Credits: 3

1. **Introduction:** Semiconductor, Junctions and Overview **2 Lectures**

2. **Two terminal MOS Structure:** Introduction, Flat band voltage, Potential Balance and charge balance, Effect of gate body voltage on surface condition, Accumulation and depletion, Inversion, CV Characteristics. **6 Lectures**

3. **Three terminal MOS Structure:** Introduction, Contacting the Inversion layer, The body effect, Regions of inversion, VCB control. **4 Lectures**

4. **Four terminal MOS Structure:** Introduction, Transistor region of operation, Complete all region model, Simplified all region models, Model based on Quasi-Fermi Potential, Regions of inversion in term of terminal voltages, strong inversion, weak inversion, moderate inversion, source referenced vs body referenced modeling, effective mobility, temperature effects. **10 Lectures**

5. **Small Dimension Effects:** Introduction, carrier velocity saturation, channel length modulation, charge sharing, drain induced barrier lowering, punch through, hot carrier effects, polysilicon depletion, quantum mechanical effects, DC gate current, junction leakage: band to band tunneling and GIDL, leakage currents. **8 Lectures**

6. **Large signal modeling:** Introduction, quasi static operation, terminal currents in quasi static operation, transit time under DC conditions, limitations of Quasi static model, non-quasi static modeling, extrinsic parasitic. **6 Lectures**

7. **Small signal modeling:** Introduction, low frequency small signal model, medium frequency small signal model, noise, all region models. **6 Lectures**

Text Books:

1. Operation and modeling of the MOS transistor by Yannis Tsividis, Oxford University Press, 2011.
2. Sze, S. M., Lee, M. K., Dhar, R. S., and Nair, A. R., “Semiconductor Physics and Devices and Indian Adaptation”, 3rd Ed., Wiley. 2021
3. The Physics of Low-Dimensional Semiconductors, John H. Davies, Cambridge University Press, 1998.

Reference Books:

1. Charge-Based MOS Transistor Modeling: The EKV Model for Low-Power and RF IC Design by Christian C. Enz, Eric A. Vittoz, Wiley, 2006.
2. Fundamental of Modern VLSI devices by Yuan Taur and Tak H. Ning, Cambridge University Press, 2nd Edition, 1998.

ECL 4X09 2D Materials and Semiconductor Physics
L-T-P: 3-0-0 Credits: 3

1.	**Basics:** Electrons in Solids, emergence behavior when forces between electrons cannot be neglected, topological aspects of the electron wavefunction, emergent quasiparticles.	**6 Lectures**
2.	**Band structure of 2D semiconductors:** Graphene, Transition metal dichalcogenides	**6 Lectures**
3.	**Quantum statistics:** Quantum-hall effect and fractional quantum hall effect, 2D-Topological insulators, Quantum spin hall effect in graphene	**6 Lectures**
4.	**Optical transitions in 2D transition metal chalcogenides:** Excitons, valley electronics, heterostructures.	**5 Lectures**
5.	**Single Photon Emission (SPE):** SPE in Nitrogen-Vacancy in diamond, SPE in 2D semiconductors.	**6 Lectures**
6.	**Twistronics:** Graphene, other 2D-materials	**5 Lectures**
7.	2D materials for quantum information science	**2 Lectures**
8.	**Other applications:** 2D thermoelectric materials, 2D perovskites, 2D Janus crystals and their superlattices.	**6 Lectures**

Text Books:

1. Quantum Theory of Materials by Efthimios Kaxiras and John Joannopoulos, Cambridge University Press; 2nd Revised ed. Edition, 2019
2. 2D Materials for Nanoelectronics by Michel Houssa, Athanasios Dimoulas, Alessandro Molle, 2016, CRC Press.
3. Solid State Theory: An Introduction by Ulrich Rössler, Springer Berlin, Heidelberg, 2009.
4. Solid State Physics, Ashcroft amd Mermin, Thomson Press (India) Ltd, 2003

Reference Books:

1. Advanced Applications of 2D Nanostructures: Emerging Research and Opportunities by Subhash Singh, Kartikey Verma, Chander Prakash, Springer 2021.
2. 2D Monoelemental Materials (Xenes) and Related Technologies, Beyond Graphene, Zongyu Huang, Xiang Qi, and Jianxin Zhong, CRC Press, 2022
3. C. Kittel, Introduction to solid state physics, Wiley, New York, 1976.

ECL 4X10 **MEMS and Microsystems**
L-T-P: 3-0-0 **Credits: 3**

No.	Topic	Lectures
1.	**Scaling Laws, Why MEMS?**	**2 Lectures**
2.	**Micro-fabrication Techniques:** Bulk micro machining, surface micro machining and LIGA processes	**6 Lectures**
3.	**MEMS based inertial sensors:** Accelerometer; piezo-resistive and capacitive.	**6 Lectures**
4.	**MEMS based gyro and tilt sensors**	**2 Lectures**
5.	**MEMS based pressure sensor:** Type Pressure Monitoring System	**2 Lectures**
6.	**Electrostatic actuation:** study of electrostatically actuated micro-machined cantilever beam: Free natural mode of vibration, resonance analysis, static voltage response, pull in and pull-out phenomenon. Dynamic response to time varying electrostatic actuation	**4 Lectures**
7.	**RF MEMS:** RF switch, MEMS based inductor and capacitors, MEMS based varactors and resonators.	**6 Lectures**
8.	**Optical MEMS:** MEMS based mirrors, MEMS based optical switch.	**2 Lectures**
9.	**Microfluidic and Bio MEMS:** advantages of MEMS based fluidic system.	**2 Lectures**
10.	Micro pump and Micro valve, Micro nozzle and thrusters, micro needle, micro cantilever-based bio sensors, lab on a chip.	**6 Lectures**
11.	**MEMS based interfacing electronics:** variable gain instrumentation amplifier and wireless integrated micro sensors.	**4 Lectures**

Text Books:

1. Analysis and design principles of MEMS devices by M.-H. Bao.
2. Microsystem Design by Stephen D. Senturia, Kluwer Academic Publishers, 2001.
3. Micro and Smart system by G. K. Ananthasuresh, K.J. Vinoy, S. Gopalakrishnan, K. N. Bhat, V. K. Aatre, Wiley, 2012.
4. Fundamentals of Microfabrication techniques, Marc Madou, CRC Press

ECL 4X11 Fundamentals of Semiconductor Materials and Devices
L-T-P: 3-0-0 **Credits: 3**

1. **Semiconductor properties and Band Structure:** Crystal structure, intrinsic and doped crystals, excess carriers and current transport, Band structure, carrier energy and Fermi distributions for free carriers, donor and acceptor impurities, determination of band gap, impurity ionization, and critical temperatures for intrinsic ionization and onset of impurity deionization, Impurity diffusion processes and profile derivations, built-in electric field and carrier profiles. **12 Lectures**

2. **Optoelectronic properties:** Optical processes in semiconductors, EHP formation and recombination, absorption and radiation, deep level transitions, Auger recombination, luminescence and time resolved photoluminescence, optical properties of photonic band-gap materials. **8 Lectures**

3. **Junction electronics:** p-n junction, tunnel diode, quasi-Fermi levels, depletion width capacitance and its application in doping profile determination, I-V characteristics of narrow and wide base diodes, breakdown mechanisms, PIN, heterojunction and avalanche photodiode, Comparisons of various photodetectors, measurement techniques for output pulse. **12 Lectures**

4. **Electronic Material and devices:** Formation of bipolar and FET transistors, current gains, drift and graded base transistors, Surface states, measurement of surface charge, Q-V/I-V characteristics, Dynamic effects of MOS capacitor, basic structure and response of charge coupled devices, buried channel charge coupled devices. **10 Lectures**

Text Books:

1. Solid State Physics, Ashcroft amd Mermin, Thomson Press (India) Ltd, 2003
2. Sze, S. M., Lee, M. K., Dhar, R. S., and Nair, A. R., “Semiconductor Physics and Devices and Indian Adaptation”, 3rd Ed., Wiley. 2021
3. The Physics of Low-Dimensional Semiconductors, John H. Davies, Cambridge University Press, 1998.

Reference Books:

1. Eshraghian, K., Pucknell, D.A. and Eshraghian, S., “Essentials of VLSI Circuit and System”, 2nd Ed., Prentice-Hall of India. 2005
2. Glover, I.A., Pennoek, S.R. and Shepherd P.R., “Microwave Devices, Circuits and Sub-Systems”, 4th Ed., John Wiley & Sons. 2005
3. Golio, M., “RF and Microwave Semiconductor Devices Handbook”, CRC Press
4. Liao, S.Y., “Microwave Devices and Circuits”, 4th Ed., Pearson Education.

ECL 4X12 **Bio-medical Electronics and Systems**

L-T-P: 3-0-0 **Credits: 3**

1.	**Bio-medical Electronics and Bio-Electric signals:** Biometrics, man-instrument system, components of the man-instrument system, problems encountered in measuring a living system, Origin of bio-electric signals, bioelectric potentials, biopotential electrodes	**16 Lectures**
2.	**Physiological Transducers:** Pressure transducers, transducers for body temperature measurement, pulse sensors, respiration sensors.	**8 Lectures**
3.	**Biomedical Recorders:** Electrocardiograph, phonocardiograph, electroencephalograph, electromyography	**8 Lectures**
4.	**Patient Monitoring System:** System concepts, measurement of heart rate, blood pressure measurement, measurement of temperature, measurement of respiration rate, apnoea detectors.	**10 Lectures**

Text Books:

1. Biomedical Instrumentation and Measurements, L. Cromwell, F. J. Weibell, E. A. Pfeiffer, Pearson Education, Delhi, 2e, 2005.
2. Biomedical Digital Signal Processing, W. J. Tompkins, PHI, 3e, 2008., 2012

Reference Books:

1. Handbook of Biomedical Instrumentation R. S. Khandpur, Tata Mc Graw Hill, New Delhi, 2e, 2003.
2. Bioinstrumentation, J. G. Webster, Wiley, 4e, 2004.

ECL 4X13 **RF Microelectronic Devices**

L-T-P: 3-0-0 **Credits: 3**

1.	**III-V opto- and high frequency materials:** Bonds, crytstal lattices, crystallographic planes and directions, direct and indirect semiconductors and their comparison for optical applications, optical processes of absorption and emission, radiative and non-radiative deep level transitions, phase and energy band diagrams of binary, ternary and quaternary alloys, determination of cross-over compositions and band structures.	**10 Lectures**
2.	**High frequency devices:** Gunn diode, RWH mechanism, v-E characteristic, formation of domains, modes of operation in resonant circuits, fabrication, control of v-E characteristics by ternary and quaternary alloys.	**8 Lectures**
3.	**Heterostructures:** Introduction, abrupt isotype/anisotype junctions, band diagrams and band off-sets, electrical and optoelectronic properties, symmetrical and asymmetrical p-n diodes and their characteristics, 2-Dimensional Electron Gas (2-DEG).	**8 Lectures**
4.	**Heterostructure FETs:** III-V NanoFETs, HEMT, quantum well and tunneling structures, strained layer structures, Advanced Nanowires QFETs.	**6 Lectures**
5.	**Miscellaneous devices:** Compound semiconductor MESFETs, infrared Lasers, Quantum cascade and Interband Laser Devices, THz QCLs, QWITT and DOVETT devices.	**10 Lectures**

Text Books:

1. Tsividis, Y., "Operation and Modeling of the MOS Transistor", 2nd Ed., Oxford University Press. 2003.
2. Sze, S. M., and Ng, K. K., "Physics of Semiconductor Devices", 3rd Ed., Wiley-Interscience. 2006.

Reference Books:

1. Arora, N., "MOSFET Models for VLSI Circuit Simulation: Theory and Practice", 4th Ed., Springer-Verlag. 1993.
2. Sze, S. M., Lee, M. K., Dhar, R. S., and Nair, A. R., "Semiconductor Physics and Devices and Indian Adaptation", 3rd Ed., Wiley. 2021.
3. Liu, W., "MOSFET Models for Spice Simulation (including BSIM3V3 and BSIM4)", Wiley-IEEE Press 2001.

ECL 4X14 Advanced System Design and Control

L-T-P: 3-0-0 Credits: 3

1. **Mathematical Descriptions of Systems:** Linear Systems, Time-variant analysis of linear systems, linearization, Discrete systems. **7 Lectures**

2. **Linear Algebra:** Basis representation and orthonormalization, similarity transformation, diagonal and Jordan form, functions of a Square Matrix, Lyapunov Equation, Quadratic form and positive definiteness, singular value decomposition. **10 Lectures**

3. **State Space Solutions, realization and Stability:** Solution of LTI State equations, equivalent State Equations, Realizations, Linear time varying equations, Input-output stability of LTI systems, Internal stability, Lyapunov Theorem, Stability of LTV Systems. **10 Lectures**

4. **Controllability and Observability:** Controllability and Observability of Indices, Canonical Decomposition, Conditions of Jordan-Form Equations, Discrete-Time State Equations, Controllability after Sampling, LTV State Equations. **8 Lectures**

5. **Minimal Realizations and Coprime Fractions:** Implications and computing of Coprime fractions, realization of Markov parameters, Degree of Transfer Matrices. **7 Lectures**

Text Books:

1. Chi-Tsong Chen, Linear System Theory and Design, 3rd Edn, Oxford University Press, 1999.

Reference Books:

1. Wilson J. Rugh, Linear System Theory, 2nd Edn, Prentice Hall, New Jersey 1996.
2. K. Ogata, Modern Control Engineering, Pearson Education, 2009.
3. B C. Kuo, Digital Control Systems, Oxford University Press, 1995.
4. M. Gopal, Control Systems Principles and Design, Tata McGraw Hill, 2012.

ECL 4X15 **Wearable and Printed Electronics**
L-T-P: 3-0-0 **Credits: 3**

1.	**Flexible electronics:** general introduction: Historical background, Materials, devices, systems, applications, Fabrication techniques, Unique aspects, status in the field and trends. Printing techniques: Basics and fundamentals, Fluid formation and rheology for printing, Inks and printing techniques, Additional coating and structuring methods	**10 Lectures**
2.	**Thin-film transistors and circuits:** Thin film transistors (TFTs), Device operation, materials, and structures, Device characterization and performance, UNIBZ's case study: sub-micrometer, Indium-Gallium-Zinc-Oxide TFTs and spraycoated carbon nanotube TFTs, Thin film circuits, From transistors to circuits, Other passive and active thin-film components, Digital and analog circuits	**11 Lectures**
3.	**Sensors and biosensors:** Sensors, Principles and fundamentals, Examples of flexible physical, chemical and optical sensors, Biosensors, Principles and fundamentals, Examples of flexible biosensors. Actuators: Principles and fundamentals, Examples of flexible optical and thermal actuators	**11 Lectures**
4.	**Energy harvesting and storage components:** Energy harvesters, Principles and fundamentals, Examples of flexible energy harvesters, Storage components, Principles and fundamentals, Examples of flexible supercapacitors and batteries. **Further processing components:** Interconnections, antennas, memories. Integrated Systems: System integration strategies, Examples of fully flexible and hybrid systems	**10 Lectures**

Text Books:
1. "Organic Flexible Electronics: Fundamentals, Devices, and Applications", P. Coseddu and M. Caironi, Elsevier, 2020.
2. "Organic and Printed Electronics: Fundamentals and Applications", G. Nisato, D. Lupo, S. Ganz, CRC Press, 2016.

Reference Books:
1. "Large Area and Flexible Electronics", M. Caironi and Y.Y. Noh, WILEY-VCH, 2015.
2. "Organic and Amorphous-Metal-Oxide Flexible Analogue Electronics", V. Pecunia, M. Fattori, S. Abdinia, H. Sirringhaus, and E. Cantatore, Cambridge Elements, 2018.
3. "Flexible Electronics: Materials and Applications", W. S. Wong, A. Salleo, Springer, 2009.

ECL 4X16 Semiconductor Optoelectronics: Theory and Design
L-T-P: 3-0-0 **Credits: 3**

1.	**Background:** carrier distributions, pn junctions, carrier injection	**2 Lectures**
2.	**Photodetectors:** absorption in bulk semiconductors, displacement currents, gain-bandwidth limits	**3 Lectures**
3.	**Modulators**: absorption in quantum wells, quantum confined Stark effect	**4 Lectures**
4.	**Optical amplifiers:** population inversion and gain, non-radiative recombination, coupled electron-photon rate equations, gain saturation, optical confinement	**5 Lectures**
5.	**Lasers:** Fabry-Perot resonators, lasing threshold	**3 Lectures**
6.	**Heterostructure materials:** optical and electrical properties of alloys, heterostructure band alignment	**3 Lectures**
7.	**Distributed feedback (DFB) and surface emitting laser resonators:** T-matrix formalism and coupled mode theory, grating based resonators	**4 Lectures**
8.	**Tunable optics:** chirp in semiconductor media, electro-optic effects	**3 Lectures**
9.	**Modulation:** small-signal and large signal analysis	**3 Lectures**
10.	**Noise in optoelectronic devices:** Langevin theory, shot noise limits, relative intensity noise (RIN) of lasers	**3 Lectures**
11.	**Systems:** WDM system design, noise and power budget for fiber optic systems	**3 Lectures**

Text Books:

1. Diode Lasers and Photonic Integrated Circuits, Coldren, and Corzine, 1st ed. New York, NY: Wiley-Interscience, October 16, 1995. ISBN: 0471118753.
2. Physics of Optoelectronic Devices, Chuang, S. L, New York, NY: Wiley-Interscience, September 8, 1995. ISBN: 0471109398.
3. Optoelectronics – An Introduction to materials and devices; Jasprit Singh, McGraw-Hill, 1996
4. Semiconductor optoelectronic devices; P. Bhattacharya, Prentice Hall India, 2006.
5. Optoelectronics - Advanced Materials and Devices; Pyshkin and Ballato, InTech, 2013

Reference Books:

1. Introduction to Organic Electronic and Optoelectronic Materials and Devices; Sun and Dalton, CRC Press, 2008.
2. Principles of Electronic Materials and Devices; Kasap; McGraw-Hill, 2005.
3. Fiber Optics and Optoelectronics, R. P. Khare, Oxford, 2004.

CSL 4XXX	**Artificial Intelligence**	
L-T-P: 3-0-0		**Credits: 3**
As per syllabus prescribed by Dept. of Computer Science and Engineering of CSL 1604		

CSL 4XXX	**Advanced Data Structures and Algorithm**	
L-T-P: 3-0-0		**Credits: 3**
As per syllabus prescribed by Dept. of Computer Science and Engineering of CSL 2101		

CSL 4XXX	**Artificial Neural Networking**	
L-T-P: 3-0-0		**Credits: 3**
As per syllabus prescribed by Dept. of Computer Science and Engineering.		

CSL 4XXX	**Humanoid Interactions and Nanorobotics**	
L-T-P: 3-0-0		**Credits: 3**
As per syllabus prescribed by Dept. of Computer Science and Engineering.		

CSL 4XXX	**Bioinformatics**	
L-T-P: 3-0-0		**Credits: 3**
As per syllabus prescribed by Dept. of Computer Science and Engineering.		

EEL 4XXX	**Renewable Energy Sources and Systems**	
L-T-P: 3-0-0		**Credits: 3**
As per syllabus prescribed by Dept. of Electrical and Electronics Engineering of EEL XX41		

CSL 4XXX	**Optimization techniques**	
L-T-P: 3-0-0		**Credits: 3**
As per syllabus prescribed by Dept. of Dept. of Computer Science and Engineering.		