M.TECH IN SEMICONDUCTOR TECHNOLOGY

- The curriculum of the two-year M.Tech. in Semiconductor Technology program comprises a total of 64 credits of which 37 credits account for course-work and 27 credits for project work. The course-work is organized as follows:

  Pool-A courses (Core): 19 credits

  Pool-B courses (For Minor): Minimum 9 credits have to taken under any one of the Minor areas in order to get a Minor in that area.

  please note, that getting a Minor is optional for students. That is, a student may choose* ***to not *take any Minor, in which case, his/her degree won't mention any Minor.*

- Electives: Remaining credits to make a total of 37 course credits.

- Soft core: There is no 'soft core' course for this program except for those opting to get a Minor in Materials, or in Quantum Tech. There are 6 credits (3 credits x 2 courses) of Soft Core, each in Materials Minor, and Quantum Tech Minor only. These are the courses which must be compulsorily credited by a student who wishes to get a Minor in either Materials or in Quantum Tech.

Pool A courses

NE 201A	3:0	Structural and functional characterization: Theory
NE 203	3:0	Advanced Micro & Nano Fabrication technology & process
NE 206	3:0	Semiconductor Device Physics: Basics Devices
NE 250	1:0	Entrepreneurship: Ethics & Social Impact
NE 201B	0:2	Structural and functional characterization: Lab
NE 202	0:2	Micro & Nano fabrication
NE 241	3:0	Material Synthesis: quantum dots to bulk crystals
NE 200	2:0	Technical Writing/Presentation

Pool B courses

			Minor in the area of
NE 215	3:0	Applied Solid State Physics	Nano-electronics
NE 223	2:1	Analog circuits & Embedded systems for sensors	Nano-electronics
NE 315	3:0	Semiconductor Devices for RF/Microwave Electronics	Nano-electronics
NE 314	3:0	Semiconductor opto-electronics and photovoltaics	Nano-electronics
NE 317	3:0	From Natural to artificial Intelligence	Nano-electronics
NE 221	3:0	Advanced MEMS Packaging	Micro-systems & packaging
NE 222	3:0	MEMS: Modelling, Design, and Implementation	Micro-systems & packaging
NE 235	3:0	Microsystem Design and Technology	Micro-systems & packaging
NE 231	3:0	Microfluidics	Micro-systems & packaging
NE 332	3:0	Physics and mathematics of molecular sensing	Nanoscience in bio
NE 281	3:0	Statistical and probabilistic data analysis techniques	Nanoscience in bio
NE 242	3:0	Nanotechnology in biology and medicine	Nanoscience in bio
NE 310	3:0	Photonics Technology: Materials & Devices	Photonics
NE 313	3:0	Lasers: Principles and Systems	Photonics
NE 311	3:0	Integrated Photonics Lab	Photonics
NE 213	3:0	Introduction to Photonics	Photonics
NE 312	3:0	Nonlinear Photonics and Lasers	Photonics
MT 202	3:0	Thermodynamics and kinetics	Materials
MT 240	3:0	Principles of electrochemistry and corrosion	Materials
MT 241	3:0	Structure and characterization of materials (soft core)	Materials
MT 209	3:0	Defects in materials (soft core)	Materials
MT 261	3:0	Organic Electronics	Materials
MT 211	3:0	Magnetism, magnetic materials and devices	Materials
NE 240	3:0	Materials design principles for electronic, electromechanical & optical functions	Materials
QT 204	3:0	Introduction to Materials for Quantum Technologies	Quantum tech
QT 202	3:0	Introduction to Quantum Measurement and Sensing	Quantum tech
QT 207	3:0	Introduction to quantum computation (soft core)	Quantum tech
QT 209	3:0	Introduction to Quantum Communications and Cryptography (soft core)	Quantum tech
QT 211	1:2	Basic Quantum Technology Laboratory	Quantum tech

Electives:
The remaining credits to make a minimum total of 37 course credits can be taken from among all courses offered in the institute with the approval of the advisor, including Pool B courses listed above.

Project:
NE 299 - 0:27 Dissertation Project

Soft core: For minors in Quantum Technology, and in Materials Engineering only. These are the courses which must be compulsorily credited by a student who wishes to get a Minor in the respective area.

Color code for Minors:

Red: Nano-electronics
Blue: Photonics
Orange: Micro-systems and packaging
Green: Nanoscience in biology
Purple: Quantum Technology (in collaboration with IISc Quantum initiative)
Pink: Materials Engineering (in collaboration with Materials Dept. at IISc)

Semester I

Course code	Course name	Core/ Elective	Instructor (primary)	Credits
NE201A	Structural and functional characterization: Theory	Core	Akshay Naik	3:0
NE 203	Advanced Micro & Nano Fabrication technology & process	Core	Shankar/ Sushobhan	3:0
NE 206	Semiconductor Device Physics: Basics Devices	Core	Sushobhan	3:0
NE 250	Entrepreneurship: Ethics & Social Impact	Core	Navakanta Bhat	1:0
NE 215	Applied Solid State Physics	Elective	Akshay Naik	3:0
NE 213	Introduction to Photonics	Elective	Shankar Selvaraja	3:0
NE 222	MEMS: Modelling, Design, and Implementation	Elective	Saurabh/ Gayathri	3:0
NE 281	Statistical and probabilistic data analysis techniques	Elective	Manoj Varma	3:0
MT 202	Thermodynamics and kinetics	Elective	Sai Gautam	3:0

Semester II

Course code	Course name	Core/ Elective	Instructor (primary)	Credits
NE201B	Structural and functional characterization: Lab	Core	Akshay Naik	0:2
NE 202	Micro & Nano fabrication	Core	Shankar/ Sushobhan	0:2
NE 241	Material Synthesis: quantum dots to bulk crystals	Core	Pavan Nukala	3:0
NE 200	Technical Writing/Presentation	Core	Shivashankar/ Sreetosh	2:0
NE 332	Physics and mathematics of molecular sensing	Elective	Manoj Varma	3:0
NE 221	Advanced MEMS Packaging	Elective	Prosenjit/ MM Nayak	3:0
NE 235	Microsystem Design and Technology	Elective	Gayathri	3:0
NE 310	Photonics Technology: Materials & Devices	Elective	Shankar Selvaraja	3:0
NE 313	Lasers: Principles and Systems	Elective	Supradeepa	3:0
NE 311	Integrated Photonics Lab	Elective	Shankar Selvaraja	3:0
NE 223	Analog circuits & Embedded systems for sensors	Elective	Saurabh Chandorkar	2:1
NE 315	Semiconductor Devices for RF/Microwave Electronics	Elective	Digbijoy/ Muralidharan	3:0
NE 314	Semiconductor opto-electronics and photovoltaics	Elective	Aditya/ Sushobhan	3:0
MT 240	Principles of electrochemistry and corrosion	Elective	Sai Gautam	3:0
MT 241	Structure and characterization of materials	Soft Core	Rajeev Ranjan	3:0
QT 204	**Introduction to Materials for Quantum Technologies**	Elective	Chandni U.	3:0
QT 202	**Introduction to Quantum Measurement and Sensing**	Elective	Baladitya Suri	3:0

Semester III

Course code	Course name	Core/ Elective	Instructor (primary)	Credits
NE 312	Nonlinear Photonics and Lasers	Elective	Supradeepa	3:0
NE 231	Microfluidics	Elective	Prosenjit	3:0
NE 240	Materials design principles for electronic, electromechanical & optical functions	Elective	Pavan Nukala	3:0
NE 317	From Natural to artificial Intelligence	Elective	Sreetosh Goswami	3:0
NE 242	Nanotechnology in biology and medicine	Elective	Vini Gautam	3:0
MT 209	Defects in materials	Soft core	Karthieyan	3:0
MT 261	Organic Electronics	Elective	Praveen Ramamurthy	3:0
MT 211	Magnetism, magnetic materials and devices	Elective	Bhagwati Prasad	3:0
QT 207	Introduction to quantum computation	Soft core	Apoorva Patel	3:0
QT 209	Introduction to Quantum Communications and Cryptography	Soft Core	Apoorva Patel	3:0
QT 211	Basic Quantum Technology Laboratory	Elective	Baladitya/ Vibhor	1:2

Content for NE 201A: Structural and functional characterization: Theory (3:0)

Topic	Instructor	No. of hours (lectures)
To build a general framework for understanding materials characterization in length & energy scales: imaging, diffraction, Fourier transform and use the basics to build the framework for understanding imaging dictated by diffraction such as XRD, electron diffraction and microscopy such as TEM. SEM to be included. Elastic vs. inelastic Energy loss/spectroscopy: XPS/XAS	Pavan/Vasu/ Sushobhan	9
Photoluminescence, Raman Spectroscopy	Ambarish	2
Confocal and fluorescence microscopy	Ambarish	2
Optical profilometer/UV-vis/ellipsometer, basics of FTIR	Manoj	3
Atomic Force Microscope, including CAFM, KPFM	Akshay	6
Basics of electrical measurements including resistivity, 4-probe, Hall, TLM, van der Pauw. Basics of SMU, multi-meter. Accuracy/sensitivity/resolution in measurements.	Digbijoy	3
Capacitance-Voltage measurement including MOS C-V	Digbijoy	3
Highly sensitive measurements, theory and working of lock-in amplifier; low frequency highly sensitive measurements	Gayathri	3
Opto-electronics measurements – how to measure detectivity, photo current and noise of photodetector, basics of LED measurements	Aditya	5
Basics of high-frequency measurement – needle probe vs CPW, oscilloscope/function generator, basics of VNA and small-signal parameters	Gayathri	4

Content for NE 201B: Structural and functional characterization: Lab (0:2)

Hands-on training on the following tools, 2 hours per tool x 10 = 20 hours

i. DC probe station
ii. RF probe station and VNA
iii. Lock-in amplifier
iv. Opto-electronic (EQE, UV-Vis, photodetector/LED measurement)
v. SEM
vi. XRD
vii. XPS
viii. AFM
ix. Raman
x. Ellipsometer

End Term project: 8 hours. One project per student/group.

Details of course content:

NE NE 200	Technical Writing and Presentation	This course is designed to help students learn to write their manuscripts, technical reports, and dissertations in a competent manner. The do's and don'ts of the English language will be dealt with as a part of the course. Assignments will include writing on topics to a student's research interest, so that the course may benefit each student directly.
NE 202	Micro and Nano Fabrication	This course is designed to give training in device processing at the cleanroom facility. Four specific modules will be covered to realize four different devices i) p-n junction diode, ii) MOS capacitor iii) MEMS Cantilever iv) Microfluidic channel.

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NE 221	Advanced MEMS Packaging	This course intends to prepare students to pursue advanced topics in more specialized areas of MEMS and Electronic packaging for various real-time applications such as Aero space, Bio-medical, Automotive, commercial, RF and micro fluidics etc. MEMS – An Overview, Miniaturisation, MEMS and Microelectronics -3 levels of Packaging. Critical Issues viz., Interface, Testing & evaluation. Packaging Technologies like Wafer dicing, Bonding and Sealing. Design aspects and Process Flow, Materials for Packaging, Top down System Approach. Different types of Sealing Technologies like brazing, Electron Beam welding and Laser welding. Vacuum Packaging with Moisture Control. 3D Packaging examples. Bio Chips / Lab-on-a chip and micro fluidics, Various RF Packaging, Optical Packaging, Packaging for Aerospace applications. Advanced and Special Packaging techniques – Monolithic, Hybrid etc., Transduction and Special packaging requirements for Absolute, Gauge and differential Pressure measurements, Temperature measurements, Accelerometer and Gyro packaging techniques, Environmental Protection and safety aspects in MEMS Packaging. Reliability Analysis and FMECA. Media Compatibility Case Studies, Challenges/Opportunities/Research frontier.
NE 235	Microsystem Design and Technology	This introductory course covers the fundamentals and analysis of MEMS transducer design and system development. This course builds on the background provided in "NE222 MEMS: Modelling, Design, and Implementation". This course exposes the students to material physics, elastic waves and propagation, transducer modelling, MEMS sensors and actuator design, and RF MEMS component analysis. The course will also have basic lab sessions where microsystems such as ultrasonic transducers, mass sensors, Surface Acoustic Wave resonators, inertial sensors, etc. will be demonstrated. Finite element modelling, layout design and device testing scheme of different MEMS transducers will be covered. The course will be evaluated using quizzes, assignments, and a project.
NE 310	Photonics technology: Materials and Devices	Optics fundamentals; ray optics, electromagnetic optics and guided wave optics, Light-matter interaction, optical materials; phases, bands and bonds, waveguides, wavelength selective filters, electrons and photons in semiconductors, photons in dielectric, Light-emitting diodes, optical amplifiers and Lasers, non-linear optics, Modulators, Film growth and deposition, defects and strain, III-V semiconductor device technology and processing, silicon photonics technology, photonic integrated circuit in telecommunication and sensors

NE 313	Lasers: Principles and Systems	This is an intermediate level optics course which builds on the background provided in “Introduction to photonics” offered in our department. Owing to the extensive use of lasers in various fields, we believe a good understanding of these principles is essential for students in all science and engineering disciplines
NE 332	Physics and Mathematics of Molecular Sensing	This course presents a systematic view of the process of sensing molecules with emphasis on bio-sensing using solid state sensors. Molecules that need to be sensed, relevant molecular biology, current technologies for molecular sensing, modeling adsorption-desorption processes, transport of target molecules, noise in molecular recognition, proof-reading schemes, multi-channel sensing, comparison between in-vivo sensing circuits and solid state biosensors.
NE 203	Advanced micro- and nanofabrication technology and process	Introduction and overview of micro and nano fabrication technology. Safety and contamination issues in a cleanroom. Overview of cleanroom hazards. Basic process flow structuring. Wafer type selection and cleaning methods. Additive fabrication processes. Material deposition methods. Overview of physical vapour deposition methods (thermal, e-beam, molecular beam evaporation) and chemical vapour deposition methods (PE-CVD, MOCVD, CBE, ALD). Pulsed laser deposition (PLD), pulsed electron deposition (PED). Doping: diffusion and ion implant techniques. Optical lithography fundamentals, contact lithography, stepper/canner lithography, holographic lithography, direct-laser writing. Lithography enhancement methods and lithography modelling. Non-optical lithography; E-beam lithography, ion beam patterning, bottom-up patterning techniques. Etching process: dry and wet. Wet etch fundamentals, isotropic, directional and anisotropic processes. Dry etching process fundamentals, plasma assisted etch process, Deep Reactive Ion Etching (DRIE), Through Silicon Vias (TSV). Isotropic release etch. Chemical-mechanical polishing (CMP), lapping and polishing. Packaging and assembly, protective encapsulating materials and their deposition. Wafer dicing, scribing and cleaving. Mechanical scribing and laser scribing, Wafer bonding, die-bonding. Wire bonding, die-bonding. Chip-mounting techniques.

NE 206	Semiconductor Device Physics: Basic Devices	Free electron model, Energy bands in solids, Reciprocal space, Direct & indirect band gap, Brillouin Zone (BZ), Fermi-Dirac distribution, Intrinsic & extrinsic semiconductors, Doping, Impurity levels & dopant population, Density of states, Effective density of states. Equilibrium electron-hole concentration, Temperature-dependence of carrier concentration, degenerate/highly doped semiconductor. Low-field transport: Scattering mechanisms & mobility. High-field transport: velocity-field relation, velocity saturation. Diffusion and Drift. Metal-semiconductor (Schottky and Ohmic) junctions, Schottky diode under bias, Fermi pinning & surface states, image force lowering. Excess carriers and recombination– Shockley-Read-Hall recombination, generation. Charge injection & Quasi-Fermi levels, current continuity equation & ambipolar transport, Haynes-Shockley experiment,. PN junction at thermal equilibrium. PN junction under forward bias, derivation of current-voltage relation. PN junction under reverse bias, generation & recombination currents. High level injection in PN diode, junction capacitance and C-V profiling. Zener & avalanche breakdown, impact ionization, punch-through effect. Transient behavior of p-n junction Transient behavior of p-n junction (contd.), diffusion capacitance, reverse recovery PN diode as solar cell and photodetector, Continuity equation under illumination. Current transport mechanisms: tunneling, thermionic field emission, space-charge or Mott-Gurney law, Poole-Frenkel, Hopping transport. Introduction to compound semiconductors, alloys, epitaxy, band engineering BJT: basic working principle, DC parameters, gain, current components. BJT: common emitter, common base operation, breakdown voltages MOS capacitor: charge, field, energy bands; concept of inversion, C-V (high F and low F), deep depletion. Real MOS cap: flat-band, threshold voltage, Si/SiO_2 system and interface/oxide traps. MOSFET: structure and operating principle, pinch-off and saturation. MOSFET: derivation of I-V, Gradual Channel Approximation. MOSFET: sub-threshold current & SS slope; device scaling and Moore's law. MOSFET: short channel effects (charge sharing, velocity overshoot, channel length modulation, DIBL, oxide reliability)

NE 213	Introduction to Photonics	This is a foundation level optics course which intends to prepare students to pursue advanced topics in more specialized areas of optics such as biophotonics, nanophotonics, non-linear optics etc. Classical and quantum descriptions of light, diffraction, interference, polarization. Fourier optics, holography, imaging, anisotropic materials, optical modulation, waveguides and fiber optics, coherence and lasers, plasmonics.
NE 215	Applied Solid State Physics	This course is intended to build a basic understanding of solid state science, on which much of modern device technology is built, and therefore includes elementary quantum mechanics. Review of Quantum Mechanics and solid state physics, Solution of Schrodinger equation for band structure, crystal potentials leading to crystal structure, reciprocal lattice, structure-property correlation, Crystal structures and defects, X-ray diffraction, lattice dynamics, Quantum mechanics and statistical mechanics, thermal properties, electrons in metals, semiconductors and insulators, magnetic properties, dielectric properties, confinement effects.
NE 222	MEMS: Modeling, Design, and Implementation	This course discusses all aspects of MEMS technology – from modeling, design, fabrication, process integration, and final implementation. Modeling and design will cover blockset models of MEMS transducers, generally implemented in SIMULINK or MATLAB. Detailed multiphysics modeling may require COMSOL simulations. The course also covers MEMS specific micromachining concepts such as bulk micromachining, surface micromachining and related technologies, micromachining for high aspect ratio microstructures, glass and polymer micromachining, and wafer bonding technologies. Specific case studies covered include Pressure Sensors, Microphone, Accelerometers, Comb-drives for electrostatic actuation and sensing, and RF MEMS. Integration of micromachined mechanical devices with microelectronics circuits for complete implementation is also discussed.
NE223	Analog Circuits and Embedded System for Sensors	The goal of this course is to explore the electronics that needs to be incorporated to create sensor systems and to learn the trade-offs in design of circuits to maximize performance subject to real life design constraints. Basic Circuit Analysis and Passive Components; Introduction to semiconductor devices and circuits involving Diodes, BJT, MOSFET and JFET; Opamp circuits: Transimpedance amplifier, Instrumentation amplifier, Comparator, Precision DMM application; Tradeoffs between power, noise, settling time and cost; Survey of sensors and their datasheets; Active Filters and RF Oscillators; Introduction to digital logic, State Machines, Digital IO; Microcontroller programming; Communication protocols for sensor interfacing; System building

NE 231	MICROFLUIDICS	This is a foundation course discussing various phenomena related to fluids and fluid-interfaces at micro-nano scale. This is a pre-requisite for advanced courses and research work related to micro-nano fluidics. Transport in fluids, equations of change, flow at micro-scale, hydraulic circuit analysis, passive scalar transport, potential fluid flow, stokes flow Electrostatics and electrodynamics, electroosmosis, electrical double layer (EDL), zeta potential, species and charge transport, particle electrophoresis, AC electrokinetics Surface tension, hysteresis and elasticity of triple line, wetting and long range forces, hydrodynamics of interfaces, surfactants, special interfaces Suspensions, rheology, nanofluidics, thick-EDL systems, DNA transport and analysis.
NE 241	Material Synthesis: Quantum Dots To Bulk Crystals	All device fabrication is preceded by material synthesis which in turn determines material microstructure, properties and device performance. The aim of this course is to introduce the student to the principles that help control growth. Crystallography; Surfaces and Interfaces; Thermodynamics, Kinetics, and Mechanisms of Nucleation and Growth of Crystals ; Applications to growth from solutions, melts and vapors (Chemical vapor deposition an Physical vapor deposition methods); Stress effects in film growth.
NE 250	Entrepreneurship, Ethics and Societal Impact	This course is intended to give an exposure to issues involved in translating the technologies from lab to the field. Various steps and issues involved in productization and business development will be clarified, drawing from experiences of successful entrepreneurs in high technology areas. The intricate relationship between technology, society and ethics will also be addressed with illustrations from people involved in working with the grass root levels of the society.
NE 312	Nonlinear and Ultrafast Photonics	This is an intermediate level optics course which builds on the background provided in “Introduction to photonics” offered in our department. Owing to the extensive use of nonlinear optical phenomena and Ultrafast lasers in various fields, we believe a good understanding of these principles is essential for students in all science and engineering disciplines, in particular students involved in the area of Photonics, RF and Microwave systems, Optical Instrumentation and Lightwave (Fiber-optic) Communications. In addition, this course intends to prepare students to pursue advanced topics in more specialized areas of optics such as Biomedical Imaging, Quantum optics, Intense field phenomena etc.

NE 314	Semiconductor Opto-electronics & Photovoltaics	Advanced semiconductor concepts, interband/intraband transitions, defects, donor-acceptor pair transitions, excitons/absorption spectra, solar radiation, PV basics, silicon p-n junction solar cell in details, thin film solar cells (amorphous Si PV, chalcogenides), organic PV, DSSC and perovskite PV, Beyond SQ limit, Photoluminescence, Advanced Photoluminescence Spectroscopy, III-nitrides and polarization, photodetectors, LEDs, OLEDs, Quantum Dot LEDs, semiconductor lasers.
NE 315	Semiconductor Devices for RF and Microwave Electronics	This course covers modern semiconductor devices commonly used in microwave electronics: heterojunction physics, III-V semiconductors including MESFETs, pHEMT and concept of 2DEG, modulation doping, fabrication of III-V FETs, RF CMOS and basics of RF MOSFET, LDMOS – working, design & RESURF, AlGaN/GaN HEMT and concept of polarization, device concepts for RF FETs including gate recess, field-plate, JFOM, small-signal performance, cut-off frequencies, current collapse & dispersion; basics of BJT/HBT for microwave; Gunn diode, IMPATT diode.
NE 317	From natural to artificial intelligence	While there are many courses on AI around the world there is no course where biology is directly correlated to device physics, and circuit design and that is the main idea behind the proposed course. The first part of the course will introduce the concepts of signal processing at synapses and how these signals contribute to storage, maintenance and recall of information. We will cover morphology and flow of electric signals in neuron, data processing in neurons and synapses, synaptic plasticity, potentiation, depression, idea of spike time dependent plasticity, ‘integrate and fire’ response in a neuron, signal transmission through axons, plasticity, reconfigurability and redundancy in a neuronal network and finally, what is the current understanding of information storage in neuronal circuit. Based on the biological foundation, the course will continue to the device and circuit design philosophy that is being taken for designing efficient AI hardware platforms. This part will focus on the static and dynamic elements being attempted to make a synapse and a neuron. The material and circuit properties to mimic the features of a neuron and a synapse will be covered. Different approaches such as FET, FTJs, memristors and neuristors will be introduced. We will discuss strategies to operate the circuit elements on the verge of chaos that can enable us to realize intelligence and decision-making ability on a chip. Towards the end of the curriculum, the students will be asked to come up with their own proposals to address specific challenges either at a device or a circuit level. This course is to narrow the gap between real and artificial neuronal networks that could offer cutting-edge exposure and motivate students to take on some of the outstanding, high reward research challenges in this field.

NE 240	Material design for electronic, electromechanical and optical functions	Module 1 [14 classes] Structure and symmetry: a) Properties as relations between cause and effect. Properties as tensors, elementary tensor algebra, matter tensors, field tensors b) Structure and symmetry: crystal systems, Bravais lattices, point groups, space groups c) Structure (symmetry)-property correlations: Neumann principle, case studies of pyroelectric properties (first rank tensor); dielectric constant, thermal/electrical conductivity (ohms law, hall effect: second rank tensors), piezoelectricity and second harmonic generation (third rank tensors), compliance/stiffness and electrostriction (4^{th} rank tensors) d) Experimental measurement of various standard properties Module 2 [8 classes] Equilibrium property predictions from thermodynamics: a) Equilibrium properties as double derivatives (or curvatures) of free energies, Cross-coupling (Stress/Strain, Polarization/Field, Temperature/Entropy). Revisit piezoelectricity/converse piezo, pyroelectricity/electrocaloric effects, thermal expansion/piezocaloric effects etc.. b) Phase transitions (first order, second order), order parameter, elementary stat-mech, equilibrium properties as fluctuation of order parameter, Landau theory c) Atomistic origin of selected equilibrium properties: piezoelectricity, electrostriction (anaharmonicity), thermal expansion (anaharmonicity); heat capacity (Debye model) Module 3 [6 classes] a) Dissipative properties as entropy generating, Onsager's formulation, electrical and thermal transport, diffusivity, electrical/thermal resistance, coupled dissipative properties: thermoelectric properties, electromigration b) Atomistic origin of electronic conductivity: Drude model, frequency dependence of conductivity, plasma frequency, conductivity (dissipative) and dielectric constant (equilibrium property) being a part of a complex dielectric function Module 4 [5 classes] a) Relation between equilibrium (fluctuation) properties and dissipative properties from Kramer-Kronig relations b) Experimental understanding of various loss processes: dissipation, energy loss and other spectroscopic tools c) Spectroscopy: impedence (nano eV energy losses), microwave spectroscopy, Brilluoin, Raman (micro-m eV), optical (FTIR, UV Vis, Photoluminiscence, UPS: 0.1-10 eV), x-ray absorption and XPS (>100 eV) Module 5 [2 classes]: Defects, defects as property deteriorating entities, defects as property enhancing entities, Recent findings on designing new properties through defects and their kinetics : some case studies

NE 281	Statistical and probabilistic data analysis techniques	Probability distributions of single r.v, PDF and CDF, , Moments, MGF, CGF, joint PDF, conditional distributions, conditional moments, Bayes theorem, PDFs of functions of r.v, Stochastic processes, simulating stochastic processes, Monte-carlo technique, auto-correlation and power spectra of random processes, estimation of PDF and CDF from data, Parameter estimation: estimators such as MLE, MMSE and Bayes, Cramer-Rao bound, Hypothesis testing: statistical significance, Neyman-Pearson approach, p-value, F-distribution, ANOVA, Introduction to design of experiments
NE 332	Physics and mathematics of molecular sensing	Introduction to biomolecules: DNA, RNA and proteins, information flow in living organisms, transcription, translation, protein synthesis and regulation, architecture of biosensors, receptors, surface functionalization and characterization techniques, antibodies and aptamers, mathematical analysis of target-receptor binding, noise and fluctuations, survey of sensor technologies, ELISA based sensing, fluorescence based sensors, genomic tests based polymerase chain reaction (PCR), plasmonic nanoparticles and lateral flow tests, single molecule sensors, transport in biosensors, current research directions
MT 202	Thermodynamics and Kinetics	Classical and statistical thermodynamics, Interstitial and substitutional solid solutions, solution models, phase diagrams, stability criteria, critical phenomena, disorder-to-order transformations and ordered alloys, ternary alloys and phase diagrams, Thermodynamics of point defects, surfaces and interfaces. Diffusion, fluid flow and heat transfer.
MT 240	Principles of electrochemistry and corrosion	Introduction to electrochemical systems, including batteries, fuel cells and capacitors. Designing electrochemical systems with emphasis on thermodynamics, kinetic, and mass transport limitations. Measuring electrochemical properties with various measurement techniques. Basic electrochemical principles governing corrosion. Types and mechanisms of corrosion. Advances in corrosion engineering and control.
MT 241	Structure and Characterization of Materials	Bonding and crystal structures, Direct and Reciprocal lattice, Stereographic projection, Point and Space Group, Point defects in crystals, Diffraction basics, X-ray powder diffraction and its applications, Scanning and Transmission electron microscopy.

MT 209	Defects in Materials	Review of defect classification and concept of defect equilibrium. Review of point defects in metallic, ionic and covalent crystals. Dislocation theory - continuum and atomistic. Dislocations in different lattices. Role of anisotropy. Dislocation kinetics. Interface thermodynamics and structure. Overview of grain boundaries, interphase boundaries, stacking faults and special boundaries. Interface kinetics: migration and sliding. Defect interactions: point defect-dislocation interaction, dislocation-interface interactions, segregation, etc.. Overview of methods for studying defects including computational techniques
MT 211	Magnetism, Magnetic Materials and Devices	A brief review of the fundamentals of solid-state physics; Classical and quantum mechanical pictures of magnetism; spin orbit coupling, crystal field environments, diamagnetism, paramagnetism, ferromagnetism, antiferromagnetism, dipolar and exchange interactions, magnetic domains, magnetic anisotropy, magnetostriction, superparamagnetism, biomagnetism, and spin glass Bulk magnetic Materials: Transition and rare earth metals and alloys. Oxide based magnetic materials. Hard, soft and magnetostrictive materials, Magnetic shape memory alloys, Structure-microstructure-magnetic property correlations. Low dimensional Magnetic systems and devices: Magnetic nanostructures, thin films, and epitaxial heterostructures; exchange bias and exchange coupling, and magneto-optical materials and devices, AMR, GMR, TMR, spin-transfer torque, spin-orbit torque and spin-Hall effect; Multiferroics, magnetoelectric and magnetoionics; nonvolatile magnetic memory, synaptic and neuromorphic computing devices; Experimental techniques: VSM, SQUID, Mossbauer, MFM, Magneto-transport, Magnetooptical Kerr-effect, TEM for magnetic characterization, XMLD and XMCD.
MT 261	Organic Electronics	Fundamentals of polymers. Device and materials physics. Polymer electronics materials, processing, and applications. Chemistry of device fabrication, materials characterization. Electroactive polymers. Device physics: Crystal structure, Energy band diagram, Charge carriers, Heterojunctions, Diode characteristics. Device fabrication techniques: Solution, Evaporation, electrospinning. Devices: Organic photovoltaic device, Organic light emitting device, Polymer based sensors. Stability of organic devices.

QT 204	Introduction to Materials for Quantum Technologies	Recap of basic solid-state physics: Electronic band structure, phonon band structure, electron-phonon interactions, electron transport and modeling in nanoscopic devices; Topology and quantum devices: Semiconductor heterostructures, two-dimensional electron systems, topological materials, introduction to superconductivity; Correlations and disorder: Electron-electron interactions, Peierls distortion and transition, disorder physics, Anderson localization, quantum devices through correlations, magnetic materials, dielectric materials and ferroelectrics, phase transitions; Optics and optical materials: Light-matter Interaction, introduction to nonlinear optical materials, optical properties of semiconductors and metals, properties of nanostructured materials, plasmonics.
QT 202	Introduction to Quantum Measurement and Sensing	Introduction to classical measurement; Introduction to quantum mechanics through measurement, the quantum measurement postulate and its consequences, standard quantum limits (SQL); Types of measurements: Direct and indirect measurements, orthogonal, non-orthogonal, quantum non-demolition measurements; Linear measurements and amplification; Beyond the SQL: Parametric amplification; Case studies of measurement: Quantised charge measurement, single photon detection, non-demolition method for photon quadrature measurements etc.; Control of single quantum systems; Introduction to decoherence: Decoherence as measurement by environment, characterising decoherence in qubits; Openloop control and stabilisation of qubit states.
QT 207	Introduction to Quantum Computation	Axiomatic quantum theory; Quantum states, observables, measurement and evolution; Qubits versus classical bits; Spin-half systems and photon polarizations; Pure and mixed states; Density matrices; General quantum evolution and superoperators; Quantum correlations; Entanglement and Bell's theorems; Turing machines and computational complexity; Reversible computation; Universal quantum logic gates and circuits; Quantum algorithms; Database search; Fast Fourier Transform and prime factorisation.

QT 209	Introduction to Quantum Communications and Cryptography	Geometrical and wave optics; Quantisation of the electromagnetic field; Photon number states, coherent states; Squeezing, phase shifts and beam-splitters; Digital communication; Communication channels; Information and entropy; Shannon's theorems; Quantum communication, dense coding and teleportation; von Neumann entropy and quantum channel capacity; Errors and error correction codes; Cryptography and one-time pad; Public and private key cryptography; Quantum key distribution; Quantum cryptography; Experimental implementation of quantum cryptography protocols.
QT 211	Basic Quantum Technology Laboratory	Introduction to RF equipment: VNA, Signal generators, AWGs, Oscilloscopes. Basics of microwave engineering: Impedence, S-parameters. Characterisation of passive RF components: Cables, Terminations, Attenuators, Directional couplers, RF mixers, Filters, Circulators and Isolators. Probability and Statistics: Binomial, Poisson and Gaussian distributions, Fitting of experimental data, Error analysis. Use of Qiskit and QuTiP Python packages for Quantum Computation and Quantum Optics: Simulation of basic quantum Hamiltonians, Dissipative systems, Quantum logic circuits.