M. Tech. in Quantum Computing
(Spl: Quantum Communication & Sensing)

About: Quantum technology is an emerging field of physics and engineering, which relies on the principles of quantum physics. It is about creating practical applications—such as quantum computing, quantum sensors, quantum cryptography, quantum simulation, quantum metrology and quantum imaging—based on properties of quantum mechanics, especially quantum entanglement, quantum superposition and quantum tunnelling. The idea of starting a quantum technology program is keeping in mind the need for high-quality human resources for India. It will be one of the world's leading academic organizations engaged in quantum technologies.

Stakeholders:

1. Sponsored candidates from Army, Navy, Air Force, DRDO Laboratories, Public Sector Undertakings and other departments.
2. Graduates in the relevant field of science/engineering from recognized Universities/Institutes across the country.

Eligibility: The candidate should possess Master degree or equivalent in Physics, Applied Physics, Electronic Science, Photonics OR B. E./ B. Tech/ BSc.(Engg.) or equivalent in Electronics Engg./ Electrical Engg./ Electrical & Electronics Engg./ Electronics & (Tele)Communication Engg./ Electrical Communication Engg./ Electronics & Instrumentation Engg./ Instrumentation Engg./ Optics & Optoelectronics.

Organization: The M. Tech. Programme is of four-semester duration. In each of the first two semesters, there are five courses and practical. There will be three continuous evaluation examinations and a final semester examination for every course. Half-yearly evaluation of the project takes place at the end of the third semester. At the end of the last semester, the student submits a thesis and makes a presentation about the project, which is evaluated by the Internal and External examiners.

Semester I

Sl No	Course Code	Course Name	Credits			Total Credits
			L	P (in Hr)	T	
1	**QT601**	Classical linear and non-linear optics and elements of quantum optics	4	0	0	4
2	**QT602**	Quantum Mechanics	4	0	0	4
3	**QT603**	Quantum Computing: An Introduction to Quantum Computers / Quantum Computing I	4	0	0	4
4	**QT604**	Quantum information theory	4	0	0	4
5	**QT605**	Digital System Design and DSP using FPGA. Control systems, and Lock-in amplifiers. FPGA implementation for quantum computation systems, QKD & post processing	3	2	0	4
6	**QT610**	Quantum Technology Laboratory-1	0	8	0	4
		TOTAL	**20**	**8**	**0**	**24**

Semester II

Sl No	Course Code	Course Name	**Credits**			**Total Credits**
			L	**P (in Hr)**	**T**	
1	**QT 606**	Advanced Quantum communications	4	0	0	4
2	**QT 607**	Quantum Metrology and Sensing	4	0	0	4
3	**QT 608**	Quantum Computing II	4	0	0	4
4	**QT 611**	Quantum Technology Laboratory-2	0	8	0	4
5		Elective – I	4	0	0	4
6		Elective – II	4	0	0	4
		TOTAL	20	8	0	24

* 1 Credit in Theory/Tutorial means 1 contact hour and 1 credit practice/Project Thesis means 2 contact hours in a week.
**Contact Hours/ week

List of Electives

Sr. No.	**Course Code**	**Course**
Elective I & II		
1	**QT 621**	Computational Photonics and optical gates
2	**QT 622**	Free Space Optical Quantum Communication
3	**QT 623**	Nanophotonics
4	**QT 624**	Non-linear Optics
5	**QT 625**	Fabrication Technology for planar Photonic devices on chip
6	**QT 626**	Post Quantum Cryptography
7	**QT 627**	RF Photonics

Semester III

Sl. No.	Course Code	Course Name	Credits		Total Credits (*)
			L	T / P	
1.	**QT 651**	M.Tech Dissertation Phase – I	28**		14
		Total	28		14

Semester IV

Sl. No.	Course Code	Course Name	Credits		Total Credits (*)
			L	T / P	
1.	**QT 652**	M.Tech Dissertation Phase - II	28**		14
		Total	28		14

QT 601: Classical linear and non-linear optics and elements of quantum optics

1. **Ray optics and Maxwell's equations:** Maxwell's equations and solution to Maxwell's equation. Paraxial waves, ray optics and ABCD matrices. Propagation of EM waves in free-space and material media. Helmholtz Equation, electric constant and refractive index. Vector and Scalar Potentials and Gauge invariance. Polarisers, Quarter, Half, and Full waveplates, Beam splitters: polarizing and non-polarizing, wavelength filters, dichroic mirrors, Lenses (**concurrent Lab Experiments**).
2. **Wave optics**: Basic postulates of wave optics, Monochromatic waves, plane waves, spherical waves, paraxial waves. Helmholtz equation. Interference of waves. The polarization of light, Stokes vector, Jones Calculus.
3. **Gaussian and special beams**: Complex amplitude of Gaussian beam, Parameters of Gaussian beam, transmission of Gaussian beams through optical components. Hermite-Gauss and Laguerre Gauss beams.
4. **Vector and vortex beams**: Orbital angular momentum of light beams and OAM states.
5. **Elements of Non-linear optics.** Second order nonlinear susceptibility: Phase matching, Second Harmonic Generation, Sum and difference frequency generation. Parametric up and down conversion. Third order nonlinearity, saturable absorption.
6. **Lasers:** Basic laser theory. Laser oscillators and amplifiers. Generation on nanosecond and femtosecond pulses. Group velocity and Pulse Dispersion. Diode laser, DPSS lasers, Distributed Fibre Laser and VECSELS.
7. **Wave guides and Optical Fibers**: Light Propagation in Optical Fibers, Optical fiber Modes and Configurations, Mode Theory for Circular waveguides, Single Mode, Multi-mode and Polarization Maintaining Fibers. Fiber Attenuation, Absorption losses, Scattering losses, Radiation losses, Bending losses, Measurement of losses, Dispersion in fibres, Effect of dispersion in communication link, Dispersion reduction and compensation techniques.
8. **Fourier Optics**: Impulse response and transfer function of free space, Fourier transform using a lens, Fraunhofer and Fresnel diffraction, Off-axis and On-axis Fourier transform holography.
9. **Quantization of the electromagnetic field:** Field quantization. Coherent states and squeezed states. Beam Splitter representation in terms of field operators. Correlation functions and photon statistics. Phase space representation and Wigner function.

References

1. B E A Saleh and M C Teich, Fundamentals of Photonics, John Wiley and Sons, 2007.
2. A. K. Ghatak and K. Thyagarajan, Lasers: Theory & Applications, Macmillan India Limited, 2003.
3. A. K. Ghatak and K. Thyagarajan, Introduction to Fiber Optics, Cambridge University Press (1998).
4. G. Kaiser, Optical Fiber communication, 4th Edition, Tata McGraw Hill, 2008.
5. A. Ghatak, Optics, TMH, 2005. 2. E. Hecht, Optics, Pearson Education India, 2012

QT 602: Quantum Mechanics

1. **Basic introduction to Quantum Mechanics:** Wave-particle duality and matter waves. The double slit experiment. The Stern-Gerlach experiment. The Schrödinger equation, square integrable functions and wavefunctions. Particle in an infinite potential well and bound states. Quantum Tunnelling. Position and momentum eigenstates.
2. **Linear algebra and complex vectors spaces:** Hilbert space. State vectors. Basis sets and the Gram-Schmidt orthogonalization. Unitary operators, operator adjoints and self-adjoint operators (Hermitian operators). Eigenvalues and eigenstates. Eigen basis and spectral decomposition of operators. The Hamiltonian operator. Position, momentum and energy eigenstates. The density operator. Complete set of commuting operators and Observables in quantum mechanics.
3. **Quantum Measurements:** Projective measurements rank one projectors. Positive Operator Valued Measures. Expectation values and Variance. The Heisenberg uncertainty relations. Pauli's exclusion principle, Fermi and Bose particles.

4. **Harmonic Oscillator, Angular momentum and other problems:** The Linear Quantum Harmonic Oscillator. Creation, annihilation operators and number operators their properties. Spin-half quantum systems and Pauli operators. The Angular Momentum problem. Time evolution of quantum systems: The Heisenberg, Schrödinger and Interaction pictures. Time evolution of density operators and the Born formula. Approximation methods.
5. **Composite systems:** Tensor product spaces. Bipartite and multipartite states. Partial trace of composite states. Schmidt decomposition. Entangled and separable systems.

References

1. Quantum Mechanics, Claude Cohen-Tannoudj, B. Diu and F. Laloë, Volume-I, WILEY-VCH, New York
2. Joachim Stoke, Dieter Suter, Quantum Computing: A *Short* Course from Theory to Experiment, WILEY-VCH GmbH & Co, 2004.
3. L.I Schiff, Quantum Mechanics, McGraw-Hill, 1968.
4. The Principles of Quantum Mechanics, Clarendon Press, Oxford, 1958.
5. David J. Griffiths, Introduction to Quantum Mechanics, Cambridge University Press, 2017
6. Kurt Gottfried, Quantum Mechanics: Fundamentals, Springer (2Ed.), 2003

QT 603: Quantum Computing: An Introduction to Quantum Computers

1. **Introduction:** Single qubit and multiqubit gates. Universal quantum gates and circuit based models of quantum computing**.** Initial ideas, Quantum algorithms, Implementations. Limitations on computer performance; Switching energy, Entropy generation and Maxwell's demon, Reversible logic, Reversible gates for universal computers, Processing speed, Storage density
2. **Quantum gates:** Single-qubit gates, Two-qubit gates and Universal sets of gates Simulating physics with computers, Quantum mechanical computers.
3. **How to build a quantum computer:** Components, Requirements for quantum information processing hardware, Converting quantum to classical information, Alternatives to the network model.
4. **Quantum error correction**
5. **Quantum computer realization:** Trapping ions; Ions. traps and light, Linear traps. Interaction with light; Optical transitions, Motional effects, Basics of laser cooling, Quantum information processing with trapped ions; Qubits, Single-qubit gates, Two-qubit gates, Readout. The Ion Trap model. Linear optical quantum computing. NMR quantum computing. Diamond color centres and Si qubits.
6. **Solid-state quantum computers:** Superconducting qubits. Josephson junction and Squids. Flux, and charge qubits.
7. **Quantum Algorithms**: Classes of quantum algorithms. Phase kick-back. Deutsch algorithm, Deutsch-Jozsa algorithm, Simon's algorithm Shor algorithm and Grover algorithm
8. **Quantum noise and error correction codes**: Noise and the Di-vincenzo criteria. The classical error correction model. The classical three bit code. Quantum error correction. Three and nine bit codes. The stabilizer codes.

References

1. Joachim Stoke, Dieter Suter, **Quantum Computing:** A ***Short*** Course from Theory to Experiment, WILEY-VCH GmbH & Co, 2004
2. Chris Bernhardt, Quantum Computing for Everyone, The MIT Press, 2019
3. Nielsen, Michael A.; Chuang, Isaac L., Quantum Computation and Quantum Information Cambridge: Cambridge University Press, 2012
4. Philip Kaye, Raymond La Flamme and Michele Mosca. An Introduction to quantum Computing, Oxford. University Press.

QT604: Classical and Quantum Information theory

1. **Classical Information theory:** Convex functions and Jensen's inequality. Shannon Entropy, mutual entropy and mutual information. Joint and conditional entropy. Data compression and codes. Kolmogorov complexity. Classical channels and Shannon coding theorems. Entropic inequalities.
2. **The Quantum bit:** The two-state system as the unit of information- The Qbit and ebit. Pure and mixed states. Bloch sphere and Poincare sphere representation of qubits.
3. **Separable and Entangled states:** Von-Neumann entropy. The Bell-state and maximally entangled states. Quantification of Entanglement: Entanglement of formation, Concurrence and entanglement monogamy. Separability of composite states. Entangled states, product states and separable systems. von Neumann entropy and negativity. The Peres-Horodecki theorem. Local unitary operations and classical communication. Quantification of entanglement. Maximally entangled mixed states. The Werner state. Local unitary operations on Bell states.
4. **Quantum decoherence and quantum operations:** Fidelity and trace distance measure between quantum states. Quantum systems coupled to environments. Bit flip, Phase Flip and depolarization channels. Amplitude and phase damping. Illustrations in the case of polarization qubits. Quantum state and process tomography with practical illustrations. The operator-sum representation and measurements.
5. **Quantum entropy:** Properties of Entropy. Conditional entropy. Quantum mutual information. Additivity sub additivity and strong subadditivity. The Holevo bound. A comparison between classical and quantum information theory.

References

1. Nielsen, Michael A.; Chuang, Isaac L., Quantum Computation and Quantum Information Cambridge: Cambridge University Press, 2012
2. Benenti, Casati, Strini, Principles of quantum computation and Information, World Scientific.

QT 605: High Performance DSP using FPGA

1. **Introduction to high performance digital computations:** Digital system design, signal processing, fixed and floating point computations, standards for high resolution computing, Design with Vivado design suite (IP, SysGen for DSP and image processing, model composer, embedded development, AI and ML tools), testing with high speed logical analyser, advanced features of modern FPGAs (Kintex-7, Virtex-7, Zynq-7000, Artix-7, Kintex UltraScale, Kintex UltraScale+,Virtex UltraScale, Virtex UltraScale+, Zynq UltraScale+ and RFSoC etc.,), external memory interface, designs with advanced VHDL, advanced design with the PlanAhead analysis/design-tools, debugging techniques using the ChipScope Pro tools, FPGA power optimization.
2. **System implementation using hybrid Simulink-programming tools:** Introduction to SysGen tools, integration of MATLAB & Simulink with SysGen platform, Model composer algorithms, integrated mixed language based design, high level synthesis, MATLAB & simulink, C and LabVIEW based HLS designs, massive parallel computations, designs with advanced XDC and STA, debugging techniques using Vivado logic Analyzer, designing with the Xilinx analog mixed signal solution.
3. **IP core library and design managements:** IP core design flow, IP core subsystems and integrations, parallelism, full/partial reconfiguration, flexible DSP blocks and multipliers, processor cores, embedded block RAM, embedded designs, standard communication interfaces, mixed signals based design, Multi-Rate Systems, MAC-Based FIR, Distributed Arithmetic and Multipliers Realization, FIFO, creating and managing reusable IPs, designs using Xilinx IP with Third-Party Synthesis Tools, Programming and Debugging Embedded Processors, SoC Processor Design, Embedded MicroBlaze Processor.

4. **Algorithm implementations using DSP tools:** Ultra fast algorithm design methodology, reconfigurable FPGA-based DSP Systems, real-time DSP System on Chip (SoC), Graphical Representation of DSP Algorithms, FIR/IIR filters, Adaptive filters, CORDIC algorithm implementations, multirate signal processing, FT/T_F analysis, spectral estimation and analysis, optimum and estimation techniques, image and speech processing, implementations of advanced transforms, Wavelet based designs.
5. **Contemporary applications and solutions:** Video and image processing, database and data analysis, control systems, high-speed, wired, wireless communications, network accelerations, test and M/m systems, HT generations/ detections, AI and machine learning algorithm implementations, 5G adaptive beamforming, RF transceiver modules interface, software driven DDS/SDR platform interface, Gbps Ethernet/optical-fiber dynamic switching, Designing an Integrated PCI Express System, IoE designs, soft controller designs.

References

1. Michael P, Digital Signal Processing 101: Everything You Need to Know to Get Started, 2010, Elsevier.
2. Steve K, Advanced FPGA Design: Architecture, Implementation, and Optimization, 2007, IEEE.
3. Sanjay Churiwala, Designing with Xilinx® FPGAs: Using Vivado, 2017, Springer.
4. Roger Woods et al., FPGA-based Implementation of Signal Processing Systems, 2017, Wiley.
5. Donald G. Bailey, Design for Embedded Image Processing on FPGAs, 2011, IEEE.
6. Uwe Meyer-Baese Digital Signal Processing with Field Programmable Gate Arrays, 2013, Springer.
7. Nasser Kehtarnavaz, Digital Signal Processing Laboratory: LabVIEW-Based FPGA Implementation, 2010, Brown Walker press.
8. https://www.xilinx.com/support.html#knowledgebase.

LIST OF EXPERIMENTS:

Sl. No.	Name of experiments
01.	The Basic Design Flow of DSP Implementation in FPGA. 1. To understand use of Xilinx System Generator. 2. To understand Xilinx Synthesis Technology or XST. 3. Familiarization of Simulink, Signal Processing Toolbox, Signal Processing Block-set.
02.	Implementation of Dual Port RAMS, Addressable Shift Register, FIFO And ROM in FPGA. 1. Familiarization with Memory Blocks implementation in FPGA. 2. To Understand FGPGA Hardware. 3. Familiarization of XUP board (Vertex-5).
03.	Implementation of M Code Adder in FPGA 1. This exercise provides an introduction to the integration of M Code into a System Generator System. 2. To understand functionality of a basic 2-input adder is interpreted from the M-code.
04.	Generation of Simulink System Period 1. To understand Simulink system periods, and confirm the meaning of this parameter from the simulation results.

QT 610: Quantum Technology Laboratory-I

1. Study of Optical lens and lens systems
2. Fibre splicing and OTDR measurement
3. Study of Polariser, Polarising and Non-polarising BS, QW, HW, FW Plates
4. Polarisation properties of laser with and without QW, HW and FW Plates
5. Fourier Optics

6. Characterization Diode laser system
7. Laser beam-divergence measurement
8. Setting up Michelson interferometer
9. Setting up Mach-Zehnder interferometer
10. Particle nature of photons
11. Demonstration of BB84 protocol
12. Quantum random number generation
13. Determination of the refractive index profile of a multimode and single mode fibre by the transmitted near field scanning technique and measurement of NA.
14. Measurement of attenuation and dispersion in optical fibres
15. WDM Mux, Demux and add drop multiplexing
16. Fibre amplifier
17. Kerr effect
18. Z-Scan

QT 606: Advanced Quantum communications

Pre-requisite: Quantum communications I

Elements of classical cryptography (basic understanding), RSA public and private key distribution, Block ciphers, American encryption standards (AES), Authentication and Wegman-Carter protocol, Universal hashing techniques, Shennon and Reni entropy, BB84 protocol, Difference between free-space and fibre-based QKD systems, Quantum teleportation and swapping, Post-processing of QKD data, Error correction and cascade protocol, Attack strategies on QKD protocols, QKD systems, Plug and play systems, Differential phase shift key (DPS), Time bin qubits & phase based techniques, The decoy state protocol, Measurement device independent QKD, Current trends in free-space and satellite QKD, QKD networks, Basic techniques of quantum optics and quantum technology

QT 607: Quantum metrology and Sensing

Introduction to laser and their applications to metrology, Coherence (spatial and temporal), Generation of pulsed lasers, mode-locked lasers, Fourier relation for time and spectral domain, Limits on resolvability (abbe diffraction limits and beat the limits of classical diffraction, classical techniques, NSOM, EIT, entangled photons, super-resolution), Fisher information, Cramer-Rao bound (classical and quantum), Standard quantum limit (shot-noise limit) and Heisenberg limit (squeezed light), Ghost imaging (quantum enhanced imaging), Quantum illumination, Quantum reading, Quantum RADAR, Super-resolution with OAM beams and vector beams, Cold atoms, Gravimeters and time-stamping based on atom interferometery, Joshpson junction and NV colour centres in diamonds for sensing

<u>Textbook/ References</u>

1. B. E. A. Saleh and M. C. Teich, Fundamentals of Photonics, 2nd ed..John Wiley, 2007
2. A. Yariv, Quantum Electronics, John Wiley.
3. Research papers/Articles as required

QT 608: Quantum computing II

Prerequisite: Quantum computing I

Unit-I: Leap from Classical to Quantum; Classical deterministic systems; Probabilistic systems; Quantum Systems; Assembling Systems
Unit-II: Computation Models; Deterministic and Nondeterministic Computations; Quantum states; Observables; Measuring; Dynamics; Assembling Quantum States; Implementation of Quantum Computers using Ion Traps, Linear Optics, NMR & Superconductors; Quantum properties

Unit-III: Bits and Qubits; Classical Gates; Reversible Gates; Quantum Gates; Pseudo and Quantum random number generators; Simulators; Uncertainties and Errors
Unit-IV: Algorithms, Deutsch's Algorithm; Deutsch's Jozsa Algorithm; Simon's Periodicity Algorithm; Grover's Search Algorithm; Shor's Algorithm
Unit-V: Programming Languages in Quantum World; Quantum Assembly Programming; Overview on Cyber security using Quantum Computers, Quantum Machine Learning
Unit-VI: Physical realization qubits introduction, Super conducting qubits and ion traps models, Linear optical quantum computing, Single qubit gates and difficulty of qubits, Circuit model for quantum computation, Computational complexities: brief introduction, models and where it is complex, How to compute quantum volume using free-accessible quantum sources from IBM and etc, Sources of decoherence and errors, Quantum error correction models and problem of scaling
Laboratory/ Practical: One demo and two lab assignments in each unit (05 Demos and 10 Assignments)

Text Book

1. Michael A. Nielsen and Isaac L. Chuang, Quantum computation and quantum information, Cambridge University Press 2010
2. Thomas H. Cormen Charles E. Leiserson Ronald L. Rivest Clifford Stein, Introduction to Algorithms, Second Edition, The MIT Press, Cambridge, Massachusetts

References

1. Robert S. Smith, Michael J. Curtis, William J. Zeng. A Practical Quantum Instruction Set Architecture. arXiv:1608.03355. 2016.
2. Eric C. Peterson, Gavin E. Crooks, Robert S. Smith. Fixed-Depth Two-Qubit Circuits and the Monodromy Polytope. arXiv:1904.10541. 2019.
3. Robert S. Smith. Someone Shouts |01000> !Who's Excited?. arXiv:1711.02086.2017.
4. Christopher M. Dawson, Michael A. Nielson. The Solovay–Kitaev Algorithm. Quantum Information and Computation. 2005.
5. Klaus Mølmer, Anders Sørensen. Multi-particle entanglement of hot trapped ions. Physical Review Letters 82. 1999.
6. Vivek V. Shende, Igor L. Markov. On the CNOT-cost of TOFFOLI gates. Quan- tum Information and Computation. 2009.
7. Vivek V. Shende, Stephen S. Bullock, Igor L. Markov. Synthesis of Quantum Logic Circuits. IEEE Transactions on Computer-Aided Design, vol. 25, no. 6. 2006.

QT 611: Quantum Technology Laboratory-II

1. Demonstration of Quantum Zeno effect
2. Tomographic single photon state reconstruction
3. Demonstration of wave nature of photons
4. Setting up Quantum eraser system
5. Test of wave particle dualism
6. Visible light interference
7. Measurement of wavelength of single photons
8. Coherence length measurement of single photons
9. Interaction-free measurement
10. Test of Bell's inequality (CHSH) violation
11. Non-classical polarization correlations
12. Tomographic state reconstruction
13. Demonstration of QKD (BBM protocol)
14. Ekert protocol – test
15. Hong-Ou-Mandel two-photon interferometers
16. Hong-Ou-Mandel interference + Hanbury-Brown & Twiss interference

17.FPGA based electronics and post-processing protocols for QKD

QT 621: Computational Photonics and optical gates

Unit-I (Mode Solver Method): Theory of fully vectorial mode solvers in 2D and 3D structures, low-index polymer waveguides, high-index silicon (SOI) and GaAs/AlGaAs waveguides, buried, etched (rib, ridge), and diffused geometries commonly used in optoelectronics slot waveguides, slanted-wall and graded structures, plasmonic and microwave waveguides, optically active and magneto-optic waveguides.
Unit-II (Beam Propagation Method): Theory and working of beam propagation method, Tutorials on MMI couplers, optical gratings, co-directional couplers or polarization converters.
Unit-III (FDTD Method): Theory and working of FDTD method, Tutorials on photonics band gap simulation: 2D and 3D of different crystal lattices.
Unit-IV (Fibre Optics): Simulation and modelling of single mode and multimode optical fibre using mode solver, FBG and Chirped FBG synthesis, photonic crystal fibre simulation
Unit-V (Nano design): Mask designing for nanofabrication of different device geometry
Unit-VI: All Optical Gate and Single Qubit photonics gate
Unit-VII: Recent advance in On-Chip Photonics based QKD
Software Tool: Suitable Commercial software tools would be used.

<u>Text/References</u>

1. S. Sujecki, Photonics Modelling and Design, CRC Press, 2015.
2. K. Okamoto, Fundamentals of Optical Waveguides, Academic Press, 2000.
3. A. Taflove, Computational Electrodynamics: The Finite-Difference Time-Domain Method. Norwood, MA: Artech House, 1995.

QT 622: Free Space Optical Quantum Communication

Unit-I (Introduction FSOC/OWC): Various modes of wired & wireless communication, Wireless access schemes, Historical perspective OWC, current scenario and challenges, Basic Link configuration of FSOC, various application areas of FSOC
Unit-II (Laser sources & Receivers for free space communications): Atmospheric low loss windows, optical sources and detectors for these windows, Characteristics of source and detectors.
Unit-III (Channel Modelling - Outdoor channel): Atmospheric channel loss, Absorption and scattering characteristics of atmosphere Fog & Visibility effects, Beam divergence, Optical & Window loss, Geometrical Loss, pointing loss, Various models of FSO in atmospheric channels, Power calculations
Unit-IV (Atmospheric turbulence effects): Atmospheric composition and structure, Significance and Measurement of Cn^2, Atmospheric Attenuation, Various atmospheric turbulence models, Basic beam propagation types, Effects of atmospheric turbulence on laser beam propagation, Realization of atmospheric effects on OWC test beds
Unit-V (Modulation Techniques): Importance of modulation in FSO, various modulation formats, Selection criteria for modulation, basic modulation schemes OOK, PPM, PIM, DH-PIM, BPSK etc. error propagation in Gaussian channels in each modulation formats
Unit-VI (FSO link Performance under atmospheric turbulence): Performance of FSO link in various modulation formats, comparison across the modulation formats, turbulence induced penalty in FSO link
Unit-VII (Mitigation techniques): Introduction, aperture averaging, various diversity techniques, spatial diversity, time diversity coding techniques, adaptive optics and other techniques
Unit-VIII (Laser beam Tracking, pointing & acquisition): Acquisition and Tracking systems, System description, Acquisition methodology, tracking and pointing control system, RF cross link system design, link equation.

Unit-IX (Free Space and atmospheric quantum Communication): Introduction, quantum sources quantum measurement processes, quantum squeezing, Measurement bases used in quantum protocols, SPDC, QKD in free space
Unit-X (Free space atmospheric quantum communication experiments): Ground-to-ground, ground to aircraft ground to satellite experiments

Text/References

1. Arun K. Majundar Advanced Free Space Optics: A systems approach. Springer publications
2. Morris Katzman, "Laser Satellite Communications", Prentice Hall Inc, New York, 1991.
3. J. Franz and V.K.Jain, "Optical Communication Systems", Narosa Publication, New Delhi, 1994.
4. Infrared Technology: Applications to Electro-Optics, Photonic Devices and Sensors, A.K.Jha

QT 623: Nanophotonics

Unit-I (Electromagnetism in Mixed Dielectric Media): The Macroscopic Maxwell Equations, Electromagnetism as an Eigen value Problem, General properties of the Harmonic Modes, Electromagnetic Energy and the Variational Principle, Magnetic vs. Electric Fields, Scaling Properties of the Maxwell Equations, Discrete vs. Continuous Frequency Ranges
Unit-II (Symmetries and Solid-State Electromagnetism): Using Symmetries to Classify Electromagnetic Modes, Continuous Translational Symmetry, Discrete Translational Symmetry, Photonic Band Structures, Rotational Symmetry and the Irreducible Brillouin Zone, Mirror Symmetry and the Separation of Modes, Time-Reversal Invariance
Unit-III (The Multilayer Film): The Multilayer Film, The Physical Origin of Photonic Band Gaps, The Size of the Band Gap, Evanescent Modes in Photonic Band Gaps , Off-Axis Propagation, Localized Modes at Defects, Surface States, Omni directional Multilayer Mirrors
Unit-IV (Metamaterial): Definition, Negative-refractive Index materials, Metamaterials as perfect lens and cloaking objects. Geometries of metamaterials.
Unit-V (Plasmonics): Evanescent waves, Surface Plasmon dispersion equations, resonance, excitation of surface plasmons, surface Plasmon properties, SPR spectroscopy, Applications of Plasmonics

Text/References

1. C. Caloz, T. Itoh, Electromagnetic Metamaterials: Transmission Line Theory and Microwave Applications, John Wiley and Sons, 2006
2. W. Cai and V. Shalaev, Optical Metamaterials, Fundamentals and Applications, Springer, 2010.
3. S. A. Ramakrishna and T. M. Grzegorczyk, Physics and Applications of Negative refractive index materials, SPIE and CRC Press, 2009.
4. Sir J. B. Pendry, Fundamentals and Applications of negative refraction in Metamaterials, Princeton University Press, 2007.
5. J. D. Joannopoulos, S. G. Johnson, J. N. Winn, and R. D. Meade, Photonic Crystal: Molding Light Flow of Light, Princeton University Press, 2008.
6. G. T. Reed and A. P. Knights, Silicon Photonics: An Introduction, JohnWiley and Sons Ltd, 2004.

QT 624: Non-linear Optics

Unit-I (Nonlinear optics basics): Simple Harmonic Oscillator model, Anharmonic oscillator model, Nonlinear polarization, Nonlinear wave equation, Nonlinear susceptibilities and mixing coefficients.
Unit-II (Second order nonlinear effects): Second harmonic generation, Phase matching condition, Various phase matching techniques, Characterization of second order nonlinear optical materials, Periodically poled materials and their applications in non-linear optical devices. Sum and difference frequency generation, Optical parametric amplification (OPA) and oscillation (OPO), Analysis of OPA and OPO; practical device configurations and applications.

Unit-III (Third order and Higher order effects): Third harmonic generation, Four wave mixing and Self phase-modulation Optical Kerr effect, Self-focusing, Optical Solitons, Optical phase conjugation and Optical bistability. Stimulated Raman Scattering and Stimulated Brilluoin Scattering.
Unit-IV (Ultrafast Optics): Introduction to ultrashort pulses, Ultrashort pulse generation through mode-locking, Nonlinear Schrödinger equation, Supercontinuum generation.

Text/References

1. R. W. Boyd, Nonlinear Optics, Academic Press, 2008
2. Peter E. Powers, Fundamentals of Nonlinear Optics, CRC Press, 2011.
3. A. M. Weiner, Ultrafast Optics, Wiley Books, 2008

QT 625: Fabrication Technology for planar Photonic devices on chip

Unit-I (Evolution of Microsystems): Benefits of micro systems, concept of micro machines/ microsystems. Scaling laws, nano machines, Silicon as a mechanical material.
Unit-II (Materials Processing Methods): Growth of Thin films, Chemical Vapour Deposition-Principles and systems, CVD growth of thin films, Molecular Beam Epitaxy, Liquid Phase Epitaxy, Vapour growth of Nitrides. Metal-organic CVD, PVD, PLD, sputter coating, spin coating, dip coating, fibre extrusion, electro spinning, Basic concepts of crystal growing, Solution growth, Melt growth, Flame fusion techniques and flux growth.
Unit-III (Etching and Lithographic techniques): Bulk etching and RIE, Top down approach to nanolithography-Immersion lithography- Optical lithography, UV photolithography- Phase lithography- Including Plasma X-ray sources- E-Beam Lithography- Focused Ion beam lithography, LIGA, Soft lithography for nano films and nano scale patterning.
Unit-IV (MEMS actuators): Electrostatic actuators, Thermal actuators, Piezoelectric Actuators, Magnetic Actuators
Unit-V (Structural MEMS): Static Bending of thin plates, mechanical vibration, thermo-mechanics, fracture mechanics, thin film mechanics, Mechanical Testing of MEMS and NEMS
Unit-VI (Packaging): Foundation of MEMS packaging, Types of Packaging: metal, ceramic, thin film multilayer packaging, plastic packaging, Chip scale packaging, Ball grid array, Multichip packaging, COF/HDI technology, Packaging in high endurance applications
Unit-VII (Case Studies): Thin films for microelectronics, optical coatings, photo-detectors, smart sensors, Pressure, strain, acceleration and vibration sensors, and micro fluidics: chemical and bio medical sensors, Examples aeronautics (control surfaces) aerospace, automobiles engineering, tire pressure sensor, structural health monitoring, biomedical engineering and intelligent consumer product design, MEMS based Infrared sources: sources for sensor application
Unit-VIII: Nano-imprint technology, Dip pen lithography, Polymer MEMS.

References

1. Physics of Semiconductor Devices by S.M. Sze, Wiley Publications (2006)
2. Mark J Jackson, Micro and Nano-manufacturing , Springer; First Edition, (2006)
3. Dieter K, Schroder, Semiconductor Material and Device Characterization, Wiley-IEEE Press, 3rd Edition, (2006) ISBN- 10:0471739065
4. L. B. Freund and S Suresh, Thin film materials: Stress, Defect formation and surface Evolution, Cambridge University Press, (2004) ISBN-10:0521822815
5. Zheng Cui, Micro-nanofabrication: Technologies and Applications, Springer First Edition(2006), ISBN-10:3540289224
6. R. Kassing, P. Petkov, W. Kulish, C. Popov., Functional Properties of Nanostructured Materials. Springer (ISBN: 978-1-4020-4595-0 (Print) 978-1-4020-4594-3 (Online)
7. Tai-Ran Hsu, 'MEMS & Microsystem, Design and Manufacture', McGraw Hill, 2002
8. Banks H.T. Smith R.C. and Wang Y.Smart, 'Material Structures – Modeling, Estimation and Control', John Wiley & Sons, New York, 1996.

9. Massood Tabib – Arar, 'Microactuators – Electrical, Magnetic Thermal, Optical, Mechanical, Chemical and Smart structures', Klumer Academic publishers, New York , 1997.
10. M. Eluenspoek, R.Wiegerink, "Mechanical Microsensors", Springer, 2001.
11. Microelectronic processing by Stephan Campbey

QT 626: Post Quantum Cryptography

Unit-I (Introduction to Post Quantum Cryptography): What Is Post-Quantum Cryptography? Comparison to Quantum Cryptography. Introduction to Mathematics of Cryptography. Classical Cryptography.
Unit-II (Hash Based Digital Signature Schemes): Hash Based One-Time Signature Schemes, Merkle's Tree Authentication Scheme, One-Time Key-Pair Generation Using an PRNG, Authentication Path Computation, Tree Chaining, Security In Merkle Signature Scheme.
Unit-III (Code-Based Cryptography): Introduction to Code-Based Cryptography, Codes and Structures, McEliece Cryptosystem.
Unit-IV (Lattice Based Cryptography): Introduction, Preliminaries of Linear Alzebra, Finding Short Vectors, Public Key Encryption Schemes, Digital Signature Schemes, Other Cryptographic Primitives.
Unit-V (Multivariate Public Key Cryptography):
Introduction, the Basics of Multivariate PKCS, Examples of Multivariate PKCS, Basic Construction and Variations.

Text Book

Post-Quantum Cryptography by Daniel J. Bernstein, Johannes, Buchmann, Erik Dahmen, Springer. ISBN: 978-3-540-88701-0.

Reference Books/Papers

1. Regev, O. 2009. School of Computer Science Tel Aviv University. Lattices in Computer Science 0368.4282. Lectures- 1, 2, 6.5.
2. Schneier, B. 1996. Applied Cryptography. John Wiley & Sons, Inc. ISBN: 0471128457
3. Research papers/Articles as required

QT 627: RF Photonics

Unit-I (Introduction to RF and Photonic Systems): Introduction to microwave photonics, basic optical and RF components: sources, modulators, receivers, passive devices, RF mixers, wireless receivers; applications of microwave photonics, fibre/wireless links: basic configuration, signal generation, transport strategies, design and analysis, advantages and limitations, high-speed optical wireless links, multiple coherent photonic RF system operations, Optically controlled phased array antennas.
Unit-II (RF signal generation and detection): Optoelectronic oscillators (generation, frequency combs); microwave photonic integrated circuits (different platforms of integration, filter designs, micro resonators, nonlinear effects), photonic based tuneable RF filter, multiple RoF and multiple RoFSO, CW, Pulsed and FMCW signal generation and detection photonic system assembly, stretch processing, Dual and multiband operations, photonics detectors for RF regeneration, PHODIR architecture.
Unit-III (Photonics signal processing): Microwave photonics signal processing: filters, photonics analog-digital-converters, true-time delay beam forming, electro-optic sampling, sampling signal generation, direct digitalisations, optical vector mixing, RF down conversion, Photonic-assisted microwave channelization (SDM,WDM, TDM), far-field/near-field AoA measurement, Ultra-Wideband free-space beam forming, SLM, optical PLL operation, wideband Programmable Microwave Photonic Signal Processing, Reconfigurable photonics,

Unit-IV (Microwave M/ms using photonics): Microwave measurements, Electronics solutions and challenges, Introduction to photonics-based broadband microwave measurements, signal parameter measurement-electric field, Phase Noise, Spectrum Analysis, Instantaneous Frequency, IF based microwave/optical power monitoring, Multiple-Frequency Measurement Based on Frequency to-Time Mapping, Doppler Frequency Shift Estimation, measurements of other signal parameters (Time-frequency analysis, Compressive sensing for a spectrally sparse signal), Software-defined solutions for photonic micro wave measurements.

Unit-V (Contemporary applications of microwave photonics): Fully Photonic based radar, single photonic multiband software defined radar, SAR/ISAR imaging, quantum radar, THz generation, sensing/imaging and beam forming, LIDAR systems, Fibre/FSO-Connected Distributed Radar System, Distributed MIMO chaotic radar based on WDM technology, Microwave Passive Direction Finding, STAR, Integrated Photonic Beam forming Architecture for Phased-Array Antennas, Future multifunctional photonics radar concepts, microwave photonics architecture for modern ultra-wide bandwidth wired/wireless communications.