M. Tech on "Quantum and Solid State Devices"

Curriculum

Department of Physics

भारतीय प्रौद्योगिकी संस्थान हैदराबाद

Indian Institute of Technology Hyderabad

Kandi, Sangareddy – 502 284

Telangana

India

Course template for M. Tech on "Quantum and solid state Devices"

Semester - 1		No. of Credits
Course name	**Course code**	
Quantum physics for engineers	**PH55010/ PH5600**	2
Mathematical and Computational methods for Quantum devices	**PH55020/ PH5610**	2
Electronic materials and Quantum devices// **Quantum devices - I (Physics of low dimensional systems and quantum devices)**	**PH55030/ PH5720**	2
Quantum optical devices	**PH55040/ PH5620**	2
Solid state devices	**PH55050/ PH5630**	2
Industrial Lectures		1
Simulations Lab	**PH55011/ PH5601**	2
Total		**13**

Semester - II		No. of Credits
Course name	**Course code**	
Quantum measurement and sensing	**PH56020/ PH5650**	2
Introduction to quantum computing	**PH5710**	2
English communications (LA)		1
Electives		8
QSD Laboratory – 2 (Experiment)	**PH56011**	2
Total		**15**
Semester 3 and Semester 4		
Project (For semester 3 and 4)	**PH56015/ PH5025**	**12+12**

Electives

S. No.	Elective title	Course code	Credits
1	Advanced quantum information, communications and Computation	**PH56110**	3
2	Fabrication and characterization of Quantum Devices	**PH56120**	2
3	Spintronics	**PH54140**	3
4	Optoelectronic Devices and applications	**PH56130**	2
6	Nano photonics	**PH56140**	2
7	Guide Wave Components and Devices	**PH56150**	2
8	Data Science Analysis	**PH54110**	3
9	Optical Devices for imaging	**PH56160**	2
10	Quantum sensors, and atomic clocks	**PH56170**	2
11	Quantum transport in nanoscale systems and devices	**PH56180**	2
12	Solid state high energy (X-ray and gamma-ray) detectors	**PH56190**	2
14	MEMS and Microsystem Technology	**PH54130**	3
15	Advanced Functional materials	**PH53120**	3
16	Advanced numerical techniques for quantum many-body physics	**PH56210**	2
17	Terahertz Devices and Applications	**PH56220**	2
18	Spin logic systems	**PH56230**	2
19	Introduction to quantum communication	**PH5730**	2

Core

Course Code: PH5600

Course Name: Quantum Physics for engineers

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Theory

Contents:

1. Early days of Quantum theory: Plank's quantization rule, Photoelectric effect, Compton effect, Heisenberg uncertainty principle, wave particle duality, de Brogle's hypothesis. [4hr]
2. The postulates of quantum mechanics, The Schrodinger equation and operators in Quantum Mechanics, commutation rules, probability density, average value of operators, potential barrier and particle in a box, importance of Hermitian and Unitary operators in quantum theory. [8hr]
3. Quantum measurement theory, collapse of wave function and Born rule. Dirac bra-ket notation, spectral decomposition, Trace rules, qubit system, superposition, coherence, density matrix, composition as tensor product, two-qubit product and entanglement states, partial trace. An overview of the importance superposition and entanglement in developing quantum technologies. [14hr]

References:

1. Quantum Mechanics: Concept and applications by N. Zettilli, (Willey & Sons, 2009)
2. Quantum Mechanics, Volume 1 by C. Cohen-Tannoudji, B. Diu, F. Laloë (Wiley & Sons, 2019)
3. Nielsen, Michael A.; Chuang, Isaac L. (2010). *Quantum Computation and Quantum Information* (10th anniversary ed.). Cambridge: Cambridge University Press.

Course Code: PH5610

Course Name: Mathematical and Computational methods for Quantum devices

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Theory

Contents:

Linear vector space, linear independent vectors, basis, span, Gram-Schmidt process, Dirac bra-ket notation, Fourier series and transform, complex variables

Basics of Numerical analysis using Python libraries; Quantum Transport computation using Non-equilibrium formalism; Use of Qiskit and QuTiP Python packages for Quantum Computation and Quantum Optics: Simulation of basic quantum Hamiltonians, Dissipative systems, Quantum logic circuits.

References:

1. G. B. Arfken, H. J. Weber and Harris Mathematical methods for Physicists, Elsevier (2012)

2. R. H. Landau, M. J. Paez, C. C. Bordeianu, Computational Physics: Problem solving with Python (2015)

Course Code: PH5720

Course Name: Electronic materials and Quantum devices/ Quantum devices - I (Physics of low dimensional systems and quantum devices)

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Theory

Contents:

Quantum physics applied to quantum wells, nanowires and quantum dots, Quantum well lasers, Optical properties of low dimensional systems (transition rules, polarization etc), Quantized conductance with Landauer-formalism. Devices based on quantum phenomena and Coulomb blockade, single electron transistor, Magnetic nanowires, Domain wall motion devices, Magnetic nanoparticles and applications to data storage, the dielectric function and optical absorption, Excitons and plasmonics, Raman scattering and photoluminescence, SQUID, Single Photon sources and detectors, quantum computers based on (a) Superconducting qubits (b) Semiconductor qubit (quantum dot) (c) Trapped ion (d) trapped atom (optical lattice) (e) Rydberg atom (f) Photons.

References:

1.John H. Davies. Physics of low dimensional semiconductors, Cambridge university press (1997)
2. A. J. Dekker, Solid state physics (1957)
3. C. Kittel Introduction to Solid State Physics, Wiley Publishing (2012)
4. J. Pagilone et. al, Fundamentals of quantum materials, World Scientific Publishing Co Pte Ltd (2021)

Course Code: PH5620

Course Name: Quantum optical devices

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Theory

Contents:

Quantum Theory of Radiation, Field Quantization, Coherent and Squeezed states of the radiation field, Atom-Field Interaction: Semi-classical and Quantum Theory, Quantum Coherence Functions, Field-Field and Photon-Photon interferometry, Experiments with a single photon, Quantum mechanics of beam splitter, interferometry with single-photon, Optical Test of Quantum mechanics, Entanglement, Bell Inequalities and Quantum Information, Introduction to Single Photon sources and detectors.

References:

1. Introductory Quantum Optics by C. C. Gerry and P. L. Knight, Cambridge University press, 2004.
2. Quantum Optics by M. O. Scully and M. S. Zubairy, Cambridge University press, 1997
3. Quantum Optics by M. Fox, Oxford Master series in atomic, Optical and Laser physics, 2007

Course Code: PH5630

Course Name: Solid State Devices

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Theory and seminar

Contents:

Introduction to Semiconductors materials, P-N junction/diode, Tunnel diode, Gunn diode, Metal-Semiconductor junction,
Bipolar Transistor: transistor (BJT)
Metal-insulator-semiconductor (MIS), Metal-Oxide-Semiconductor (MOS) diode, Charge coupled devices (CCD). Field Effect Transistor, MISFET, MOSFET, CMOS, FinFET

References:

1. Ben Streetman and Sanjay Banerjee, Solid State Electronic Devices, Pearson; 6th edition, 2013.
2. Donald A. Neaman, *Semiconductor Physics and Devices,* Tata McGraw-Hill, 2003

Course Code: PH5601

Course Name: Lab – 1 (Simulations)

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Lab, simulations

Contents:

1. Simulations using Qiskit and QuTiP Python simulation for quantum protocols
2. Two dimensional thin films - Magnetization simulations
3. Quantum dense coding
4. Quantum teleportation
5. Entanglement swapping
6. BB84 and BB92 QKD protocols
7. Quantum networks

References:

1. Michael A. Nielsen and ISSAC L. Chuang, Quantum computation and quantum information (Cambridge press) (2010).
2. Sergey Edward Lyshevski, Nano and molecular electronics handbook (2018)

Course Code: PH5650

Course Name: Quantum measurement and sensing

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Theory

Contents:

Classical Noise, Quantum noise,Time evolution of Quantum States, Bosons vs. Fermions, Bosonic Harmonic oscillator, two level atoms, fluctuations - dissipation theorem, vacuum fluctuations, Quantum detectors, classical detectors, single photon avalanche detectors, superconducting detectors, quantum interference, quantum non - demolition measurement, signal to noise ratio, quantum Fisher information, coherent states and squeezed states, quantum interferometry, nitrogen vacancy in diamond, quantum phase transition based sensing detectio**n,** superconducting single photon detectors, Foundations of quantum metrology, quantum sensing devices

References:

1. Quantum Measurement Theory and its application, Kurt Jacobs, Cambridge University Press (2014).

2. Quantum Metrology: Foundation of Units and Measurements, Ernst O. Goebel, Uwe Siegner, Wiley-VCH (2015).
3. Introduction to Quantum Metrology, Waldemar Nawrocki, Springer (2019)

Course Code: PH5710

Course Name: Introduction to Quantum Computing

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Theory

Contents:

1. Introduction: Importance of quantum computing: Potential for exponential speedup in specific problems; History of quantum computing: From Feynman's 1982 proposal to modern NISQ devices. Classical bits vs. qubits: Qubit state representation; Quantum measurement and superposition; Concept of entanglement and Bell states.

2. Quantum Gates: Single-qubit gates (Pauli, Hadamard, phase, rotation gates); multi-qubit gates (CNOT, SWAP, Toffoli); Representing algorithms as quantum circuits; Universality of gate sets; The no-cloning theorem. Introduction to Qiskit.

3. Quantum Algorithms: Deutsch's and Deutsch-Jozsa algorithms; Simon's algorithm; Quantum Fourier Transform (QFT); Grover's algorithm for unstructured search; Shor's algorithm for factorization; Simulating quantum systems. Qiskit examples.

4. Quantum Error Correction: Models for quantum noise and errors like bit flips, phase flips, and decoherence; Quantum error correction codes such as the Shor and Steane codes; The stabilizer formalism; Calderbank-Shor-Steane (CSS) codes; Fault-tolerant quantum computing concepts: threshold theorem, basic idea of topological and surface codes. Qiskit examples.

5. Applications of Quantum Computing: Quantum cryptography, including the BB84 protocol; Quantum optimization using QAOA and VQE; Quantum machine learning; Quantum chemistry simulations; Quantum annealing. Qiskit examples.

References:

1. Nielsen, M. A., & Chuang, I. L. (2010). *Quantum Computation and Quantum Information*. Cambridge University Press.

2. Djordjevic, I. B. (2021). *Quantum Information Processing, Quantum Computing, and Quantum Error Correction: An Engineering Approach* (2nd ed.). Academic Press.

3. Kaye, P., et al. (2007). *An Introduction to Quantum Computing*. Oxford University Press.

4. Mermin, N. D. (2007). *Quantum Computer Science*. Cambridge University Press.

5. Hidary, J. D. (2021). *Quantum Computing: An Applied Approach*. Springer

Course Code: PH56011

Course Name: QSD Laboratory – 2 (Experiment)

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Laboratory, experiment

Contents:

1. Quantum tunneling using an STM tip
2. Design and development of memory devices
3. Photodetectors - Detector rise-time,
   bandwidth, sensitivity, responsivity, dark current.
4. Coherence characteristics of emitters
4. Fourier optics and image processing
5. Nuclear magnetic resonance
6. Microwave- Dielectric constant
7. Single photon detector
8. Conductance of nano-device under external perturbation
9. Magnetic field sensor
10. Quantum Eraser
11. Quantum Cryptography Analogy

References:

1. Anton Zeilinger, Daniel Greenberger, W.L. Reiter, Epistemological and Experimental Perspectives on Quantum Physics (2013)
2. Mark Beck, Quantum Mechanics theory and Experiment (2012)
3. David Prutchi, Exploring Quantum Physics through Hands-on Projects (2012)

Electives

Course Code: PH56110

Course Name: Advanced Quantum information, communications and Computation

Credits: 3

Pre-Requisites (if any): Basic of quantum mechanics, foundations and communication protocols

Nature of Course: Theory

Contents:

Quantum secure communication: Bennett-Brassard QKD protocol, Bennett-92 protocol, Ekert-91 protocol using entanglement, Device-independent QKD, Communication complexity, Notion of certified quantum communication, Robust self-testing of quantum devices, QKD over a noisy channel, device-independent quantum cryptography, self-testing of quantum instruments through Bell experiment, Various forms of attacks and security of device-independent QKD

Randomness certification: Role of random numbers in physics and society, pseudo random number generation, genuine random numbers, randomness expansion and generation, Device-independent certification of randomness

Quantum Algorithms: Black-box problems**,** Deutsch's algorithm, *n*-bit Walsh-Hadamard operation and the Deutsch-Jozsa problem. Quantum oracle and Quantum parallelism. The Bernstein-Vazirani algorithm. Quantum Fourier Transformation and circuit for implementing it, Shor's factoring algorithm and analysis of its efficiency Computational Complexity, Quantum error correcting code, Shor's 9-bit code and Stabilizer codes.

References:

1. Quantum Computation and Quantum Information theory by Nielsen and Chuang (Cambridge University press, 2003)

2.Quantum information theory by Mark Wild (Cambridge University Press, 2018)

Course Code: PH56120

Course Name: Fabrication and characterization of Quantum Devices

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Theory and Lab visits

Contents:

X - ray diffraction (XRD), Neutron diffraction (ND), electron diffraction (ED), Scanning probe microscopy (SPM), secondary electron microscope (SEM), transmission electron microscope (TEM), Optical microscopy, 2-probe, 4-probe, Hall effect, UV-visible, Ellipsometry, Raman spectroscopy, Photo luminescence, Fourier transform infrared spectroscopy (FTIR), differential scanning calorimetry (DSC), Specific heat, Thermal conductivity, Thermoelectrics, Growth, chemical varpor deposition (CVD), thermal, pulsed laser deposition (PLD), sputtering, molecular beam epitaxy (MBE), Patterning, Device, superconducting quantum interference device (SQUID), vibrating sample magnetometer (VSM), magneto optical Kerr effect (MOKE), X - ray magnetic circular dichroism (XMCD), Magnetic tech., Low temperature measurements and techniques, Sputtering, thermal/e-beam evaporation, E - beam lithography, Photolithography

References:
Robert C. Richardson , Eric N. Smith Experimental Techniques In Condensed Matter Physics At Low Temperatures (1998)

2. M. I. Pergament, Methods of Experimental Physics CRC Press; 1st edition (10 December 2019)

Course Code: PH56130

Course Name: Optoelectronic Devices and applications

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Theory

Contents:

Optoelectronic materials - Semiconductors, compound semiconductors, direct and indirect bandgap, electronic characteristics of semiconductors. Optical properties of semiconductors – radiative and nonradiative recombination. Semiconductor light sources - Light-emitting diodes (LED), device configuration and efficiency, Laser diodes – basic concepts, heterojunction, and injection lasers, output characteristics. Modulators - Phase and amplitude modulators, acousto-optic modulators, magneto-optic effects. Semiconductor Photodetectors - Types of photodetectors- performance criteria of a photodetector- Optical modulators, modulation methods and modulators,

Potential experiments for Hands-on training

1. Laser diode (LD) - Total Output Power, radiation pattern, spectral bandwidth, rise time, Intensity vs drive current

2. Light Emitting Diode (LED) - Total Output Power, radiation pattern bandwidth, Intensity vs drive current.

3. Characteristics of Photodetectors - Detector rise-time, bandwidth, sensitivity, responsivity, dark curren

References:
Semiconductor optoelectronic devices- Pallab Bhattachraya, PHI, ISBN-978-81203-2047-5 (2009)

AmnonYariv,Optical Electronics, Holt Rine hart & Winston, Philadelphia, 1991

Course Code: PH56140

Course Name: Nano photonics

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Theory

Contents:

Nanophotonics: Background, Maxwells equations, Light-matter interaction, Dispersion, EM properties of nanostructures, General concepts of Plasmonics and Metamaterials, Gold & silver particles for nanophotonic devices, Metal optics, Silicon nanophotonics, Manipulating light with plasmonic nanostructures, Plasmonic nano-sensors, Refractory plasmonics, Plasmonics for energy conversion, data storage and biomed applications, Bandgap engineering of nanoscale devices, Thin films, Quantum wires and dots, Quantum Confinement based light sources and detectors, optical tweezers, photonic crystal fibers, photonic crystal devices, Metasurfaces, Quantum metamaterials, Intro to quantum photonics.

References:

1. Fundamentals of Photonics , B.E.A. Saleh, M.C. Teich , John Wiley & Sons , 1991

2. Near-field optics and surface plasmon polaritons , Satoshi Kawata , 2001

3. Optics , Hecht , Addison Wesley , 1990

4. Photonic Crystals: Molding the Flow of Light , J.D. Joannopoulos, R.D. Meade, J.N. Winn, Princeton University Press , 1995

5. Plasmonics, Stefan Mayer , Cambridge Press , 2007

Course Code: PH56150

Course Name: Guide Wave Components and Devices

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Theory

Contents:

Introduction to Waveguides

Introduction to waveguides, light propagation in waveguides/optical fibers: fiber types and numerical aperture, ray analysis of propagation of light in a fiber; loss mechanisms in fibers; signal attenuation;

Propagation Characteristics

Modal analysis of step-index fibers, characteristic equation, type of modes, single-mode fibers, mode cutoff, and mode field diameter, pulse dispersion in single-mode fibers; chromatic and intermodal dispersion, fiber bandwidth and birefringent fibers and polarization mode dispersion

Guided Wave Components

Couplers, Isolators, and Circulators; Multiplexers and Filters: Gratings, Fiber Bragg Gratings(FBG), Fabry-Perot Filters, Multilayer Dielectric Thin-Film Filters, Mach-Zehnder Interferometers, Acousto-Optic Tunable Filter;

Potential experiments for Hands-on training

0. Handling of fibers

- Basic Fiber cutting and polishing and launching light
- Different types of fibers, Fiber Optic Association (FOA) standards for cable and end connectors, or fiber ferrules

1. Optical Power measurements

- measurements of coupling loss, misalignment loss, connector loss etc

Characterization of fibers

(i) <u>Passive fibers</u>

2. Measuring fiber attenuation using Cutback method

3. Measurement of numerical aperture of fiber

4. Bend Loss of fibers

5. Fiber Dispersion measurements

(ii) <u>Active fibers</u>

6. Fluorescence measurement of active fibers

7. Fluorescence lifetime measurement of active fibers

8. Measuring fiber gain of active fibers – Erbium-doped fibers

9. Characterization of Guided Wave Components

- Couplers, Isolators and Circulators; Multiplexers and Filters:

Fiber Optics Communication

10. Design of Fiber Optics WDM link

11. Characterization of WDM link – Study BER and Q-factor

References:

1. Ghatak A and Tyagarajan K, "Introduction to Fiber optics", Cambridge University Press, 1998.
2. B. Pal, Guided Wave Optical Components and Devices, Academic Press, 2006.
3. Fundamentals of Photonics, B. E. A. Saleh and M. C. Teich, 2nd Ed., Wiley, 2007.
4. Thyagarajan K and Ghatak A., Fiber Optic Essentials, Wiley Interscience, 2007.
5. Keiser, Gerd: Optical Fiber Communications, 4th Ed., McGraw Hill (2009).

Fiber Optic Communication by G.P. Aggarwal, 5th Edition, Wiley, 2021.

Course Code:PH56160

Course Name: Optical Devices for imaging

Credits: 2

Pre-Requisites (if any): Optics and Photonics, Electrodynamics, Fourier Optics

Nature of Course: Theory combined with Designing in optics simulation tools

Contents:

The fundamental principles of optics and optical phenomena, the polarization properties of light, reflection and refraction, coherence and interference, Fresnel and Fraunhofer diffraction regimes, Fourier optics; incoherent and coherent 2-D imaging systems; image resolution; optics of the eye; principles of 3-D imaging systems (near eye and projection); static and dynamic holographic imaging systems (including photorefractive systems); electro-optic, liquid-crystal spatial light modulation; 2-D emissive displays such as OLEDs; lasers, principles of image detectors for the visible and infrared; 2-D and 3-D optical image storage technologies; adaptive optical imaging systems.

References:

1. Modern Optical Engineering, 4th Ed.: The Design of Optical Systems: Warren J Smith (2008)
2. Introduction to Fourier Optics: Joseph Goodman (2016)
3. Laser Electronics: Joseph T Verdeyen (1995)

Course Code: PH56170

Course Name: Quantum sensors, and atomic clocks

Credits: 2

Pre-Requisites (if any): Quantum Mechanics

Nature of Course: Theory

Contents:

Quantum sensing, Quantum sensors, Atomic vapours, cold atomic clouds, trapped ions, Rydberg atoms, atomic clocks, solid state spins, superconducting circuits, Sensing of signals, Noise spectroscopy, Quantum phase estimation, Adaptive phase estimation, Entangled states, quantum logic clock

References:

1. Nielsen, M. A., and I. L. Chuang (2000), Quantum computation and quantum information (Cambridge University Press, Cambridge; New York).
2. Wiseman, H., and G. Milburn (2009), *Quantum measurement and control* (Cambridge University Press).
3. Budker, D., and D. F. J. Kimball (2013), *Optical Magnetometry, by Dmitry Budker , Derek F. Jackson Kimball, Cambridge, UK: Cambridge University Press, 2013*.

Course Code: PH56180

Course Name: Quantum transport in nanoscale systems and devices

Credits: 2

Pre-Requisites (if any): Quantum Mechanics

Nature of Course: Theory and simulation

Contents:

Scattering: Wave properties of electrons, Quantum contacts, Scattering matrix and the Landauer formula, Multi-terminal circuits, Quantum interference, Andreev scattering, Spin-dependent scattering
Classical and semiclassical transport: Electron transport in solids, Semiclassical coherent transport, Reservoirs, nodes, and connectors; Ohm's law for transmission distribution, Spin transport, Circuit theory of superconductivity, Coulomb blockade, Charge quantization and charging energy, Single-electron transfers, Co-tunneling, Macroscopic quantum mechanics, Josephson arrays, Superconducting islands beyond the Josephson limit
Randomness and interference: Random matrices, Energy-level statistics, Statistics of transmission eigenvalues, Interference corrections, Strong localization
Qubits and quantum dots: Quantum computers, Quantum manipulation, Quantum dots, Charge qubits, Phase and flux qubits, Spin qubits

Interaction, relaxation, and decoherence: Quantization of electric excitations, Dissipative quantum mechanics, Tunneling in an electromagnetic environment, Relaxation and decoherence of qubits, Relaxation and dephasing of electrons

References:

1. S. Datta, Electronic transport in mesoscopic systems, Cambridge University Press (2013)
2. S. Datta, Quantum Transport: Atom to transistor, Cambridge University Press (2005)
3. Y. V. Nazarov, Y. M. Blanter, Quantum transport. Introduction to Nanoscience Cambridge University Press (2010)

Course Code: PH56190

Course Name: Solid state high energy (X-ray and gamma-ray) detectors

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Combined theory and lab

Contents:

Interaction of X-ray and Gamm-ray photon with Matter- Photoelectric absorption, Compton scattering, electron-positron pair production, general properties of solid state detectors - energy resolution, efficiency, pulse height spectra, deadtime. Germanium Gamma ray detector - operational characteristics, configurations, spectroscopy. Introduction to advanced solid state detectors - silicon drift detector, avalanche detector, photoconductive detector and position-sensitive Cadmium Zinc Telluride detector

References:

1. Radiation Detection and Measurement - 4th Edition - Glenn F Knoll (2010)
2. Techniques for Nuclear and Particle Physics Experiments - W R Leo (1994)

Course Code: PH56210

Course Name: Advanced numerical techniques for quantum many-body physics

Credits: 2

Pre-Requisites (if any): Mathematical and computational methods for quantum devices (1st sem core course)

Nature of Course: Numerical simulation techniques (Theory+Lab)

Contents:

Dynamics of Gaussian systems using covariance matrix, with and without dissipation. Building and exact diagonalization of Hamiltonians of quantum spin chains. Sparse matrix techniques for (i) properties of spectrum via Kernel Polynomial method, (ii) dynamics via Chebyshev polynomial and Krylov subspace methods. Tensor network techniques for dynamics of quantum spin chains and classical simulation of quantum algorithms.

References:

1. The kernel polynomial method, Alexander Weiße, Gerhard Wellein, Andreas Alvermann, and Holger Fehske, Rev. Mod. Phys. 78, 275 (2006).
2. Time-evolution methods for matrix-product states, Sebastian Paeckel, Thomas Köhler, Andreas Swoboda, Salvatore R. Manmana, Ulrich Schollwöck, Claudius Hubig, Annals of Physics, 411, 167998 (2019).
3. What Limits the Simulation of Quantum Computers? Yiqing Zhou, E. Miles Stoudenmire, Xavier Waintal, Phys. Rev. X 10, 041038 (2022).

Course Code: PH56220

Course Name: Terahertz Devices and Applications

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Theory combined with small project

Contents:

This course will provide a foundation for understanding the unique specifications of terahertz (THz) radiation, components of THz technology, and the physical principles of THz applications. Topics covered in this course are the various building blocks of the THz technology, sources, detection, manipulation of the THz radiation, terahertz electronics, optics and photonics. We will introduce THz applications in the domain of imaging, sensing, communications, non-destructive testing and evaluations, communications, security, space science, the pharmaceutical industry and quantum circuits/devices. The second part of the course will be a short project work related to the topics covered in the lecture. The learning from the project should be presented through a short writeup and presentation.

References:
1) Terahertz Spectroscopy: Principles and Applications. United States, CRC Press, 2017.
2) Lee, Yun-Shik. Principles of terahertz science and technology. Vol. 170. Springer Science & Business Media, 2009.
3) Ali Rostami, Hassan Rasooli, and Hamed Baghban, Terahertz Technology: Fundamentals and Applications, Springer 2010

Course Code: PH56230

Course Name: Spin logic systems

Credits: 2

Pre-Requisites (if any): Solid state physics/devices

Nature of Course: Theory, Design, Simulation

Contents:

1. Nanomagnetic logic
2. Domain wall logic
3. Skyrmion logic
4. Skyrmion qubit
5. Magnon logic
6. Magnon based hybrid qubit
7. Spin-based neuromorphic computing

References:

1. Principles of Nanomagnetism, A. P. Guimaraes, Springer (2009)
2. Magnetigzation oscillation and waves, A. G. Gurevich and G. A. Melkov, CRC press (1996)
3. Magnetic domains, Alex Hubert and Rudolf Schafer, Springer (1998)

Course Code: PH5730

Course Name: Introduction to quantum communication

Credits: 2

Pre-Requisites (if any): NA

Nature of Course: Theory

Contents:

1. The basic of communication complexity, Shannon entropy, Holveo's theorem, briefly Shannon's coding theorems.
2. Basic quantum communication protocols, dense coding, quantum teleportation, remote state preparation, swapping of two-qubit entanglement, extension to communication in large network
3. Communication games with or without seed randomness and the nature of classicality. The prepare-measure games, entanglement assisted games, entanglement assisted prepare-measure game, sequential measurement game. The non-classical measurements, entangled measurement and incompatible measurements as resource.

References:

Nielsen, Michael A.; Chuang, Isaac L. (2010). *Quantum Computation and Quantum Information* (10th anniversary ed.). Cambridge: Cambridge University Press.

Watrous, John (2018). The Theory of Quantum Information(1st ed). Cambridge: Cambridge University Press.