Pandit Deendayal Petroleum University

School of Solar Energy

M. Tech. Programme in **Energy Systems & Technology**

(focused on Solar Energy Technologies)

Course structure for **M. Tech.** Programme in **Energy Systems & Technology** (focused on Solar Energy Technologies)

Semester - I

Course No	Title	L-T-P	Credit
	Core courses		
SSE501	Mathematical Techniques	3–0–0	6
SSE502	Quantum Mechanics & Semiconductors	3-0-0	6
SSE503	Thermodynamics & Heat Transfer	3-0-0	6
SSE504	Vacuum Science & Thin Film Technology	3-0-0	6
SSE505	Renewable Energy & Energy Management	3-0-0	6
SSE506	Laboratory work/ Energy Lab-1	0-0-4	2
		TOTAL	**32**

Semester - II

Course No	Title	L-T-P	Credit
	Core courses		
SSE511	Photovoltaic Science & Engineering	3-0-0	6
SSE512	Solar Thermal Engineering	3-0-0	6
SSE513	Semiconductor Processing & Characterization	3-0-0	6
SSE514	Modeling & Simulation	3-0-0	6
SSE515	**Elective I**	2-0-0	4
SSE516	Seminar	0-0-4	2
SSE517	Laboratory Work/Energy Lab-2	0-0-4	2
		TOTAL	**32**

Semester - III

Course No	Title	L-T-P	Credit
SSE520	**Elective II**	2-0-0	4
SSE521	Project & Seminar	0-0-8	4
SSE522	M.Tech Thesis – Interim Report	0-0-16	8
SSE523	Professional Communication	0-1-0	audit
		TOTAL	**16**

Semester - IV

Course No	Title	L-T-P	Credit
SSE531	Seminar	0-0-4	2
SSE532	M.Tech Thesis	0-0-24	12
		TOTAL	**14**

Summer Research internship (in-house or in industry) – 10 credits

List of elective courses:

1. Wind Energy Generation
2. Power Electronics & Systems
3. Utilization of Solar Thermal Energy
4. Semiconductor Device Modeling
5. Silicon Photonics & Solar Cell Technologies
6. Advanced Solar Cells
7. Energy Storage Systems
8. Optimization Techniques
9. Design of Heat Exchangers
10. Fundamentals of Nuclear Energy

Core courses Outline:

Course code	Course Name	L-T-P	Credit
SSE501	Mathematical Techniques	3–0–0	6

Content:

Differential equations of higher order including partial differential equation; Infinite and power series. Vectors: vector algebra in 2 and 3 spaces, vector calculus in multiple variables, gradients, divergence, curl, line integral, Green's theorem, surface integral, Stoke's Theorem, Applications. Matrices: basic concepts (addition, multiplication, rank, linear independence etc), Inverse of matrix, solutions of linear systems, Eigen values, eigenvectors, symmetric matrices, complex matrices. Different transformations: Fourier, Laplace, Z transform, etc. Data analysis and probability theory; Mathematical statistics. Complex Analysis: Complex Analytic Functions, Complex Integrals, Laurent Series, Complex Integration by Method of Residues, Conformal Mapping and Applications

Books & References:

[1] E. Kreyszig, Advanced Engineering Mathematics 9th ed, John wiley sons.
[2] Arfken and Weber, Mathematical Methods for Physicists 6th ed. Elsevier (2005).
[3] KF Riley, MP Hobson, SJ Bence,Mathematical Methods for Physics and Engineering 3rd ed., Cambridge 2006.
[4] Earl A. Coddington, An Introduction to Ordinary Differential Equations. Prentice-Hall India (1968).
[5] Mark J. Ablowitz and Athanassios S. Fokas Complex Variables: Introduction and Applications (Cambridge Texts in Applied Mathematics), Cambridge, (2003)
[6] Tristan Needham, Visual Complex Analysis. Oxford University Press (1999).

Course code	Course Name	L-T-P	Credit
SSE502	Quantum Mechanics & Semiconductors	3-0-0	6

Content:

Wave Packets and Free-Particle Motion, Probability and Quantum Mechanics, Dynamical Variables and Operators, Properties of Operators; One-Dimensional Potential Problems, Multiple quantum Wells, One-Dimensional Harmonic Oscillator; Three-Dimensional Problems, Experimental evidence of Spin Angular Momentum, Addition of Angular Momentum; Density of States, the Fundamental Postulate of Statistical Mechanics, Connection to Classical Thermodynamics, The Grand Partition Function, Quantum Distribution Functions, Boltzman's equation for Nonequilibrium Statistical Systems; Multielectron Systems and Crystalline

Symmetries; Motion of electrons in Periodic Potential, Effective Mass Theory and the Brillouin Zone, the Kronig-Penny Model, The Nearly- Free-Electron Model, Energy Bandgaps and the Classification of Solids, Holes, k.p Calculation of Band Structure of Semiconductors, phonon and scattering mechanisms in solids, generation and recombination processes in semiconductors.

Books & References:

[1] K. F. Brennan, The Physics of Semiconductors,Cambridge University Press, 1999.
[2] Ramamurti Shankar,Principles of Quantum Mechanics, 2nd Edition, Springer, 1994.
[3] Bransden & Jochain, Quantum Mechanics, 2nd Edition, Pearson Press,2000.
[4] N. W. Ashcroft and N. D. Mermin, Solid State Physics, Latest Edition,
[5] Charles Kittel, Introduction to Solid State Physics, 8th Edition, Wiley,2004.

Course code	Course Name	L-T-P	Credit
SSE503	**Thermodynamics & Heat Transfer**	**3-0-0**	**6**

Content:

Fundamental concept: Thermodynamic system and control volume, Thermodynamic properties, Processes and cycles, Thermodynamic equilibrium, Quasi-static process

First Law of Thermodynamics: Various types of energies, First law for a closed system and open system

Second Law of Thermodynamics: Kelvin-Plank and Clausius' statements, equivalence of the statements, Causes of irreversibility, Carnot theorem and its corollary, Thermodynamic temperature scale

Entropy: Clausius theorem, The property of entropy, inequality of Clausius, Principle of increase of entropy and its application

Available Energy, Exergy and Irreversibility – High and low grade energy, Available and unavailable energy, availability (exergy) of closed; steady flow; and open system processes, irreversibility

Thermodynamic Cycles: Rankine cycle, Joule cycle, Sterling cycle, Otto, Diesel and Dual cycles

Conduction – Derivation of generalized equation in Cartesian and cylindrical coordinates, one-dimensional steady state heat transfer equations for slabs, cylinders, spheres use of electrical analogy, one dimensional transient heat conduction in solids, Necessity of extended surfaces, heat transferred under different boundary conditions, fin effectiveness and fin efficiency, Critical thickness of insulation

Radiation – Concept of black and grey surfaces, various laws of radiation, heat exchange between black and grey surfaces and enclosed body and enclosure, radiation shield and their effects, use of electrical analogy methods

Convection – Dimensionless number and their use, derivation of generalized equation in dimensionless groups for free & forced convection by dimensional analysis and principle of similarity, use of empirical co-relations to determine heat transfer co-efficient in natural and forced convection

Books & References:

[1] Engineering Thermodynamics by P K Nag
[2] Fundamental of Classical Thermodynamics by Wan Wylen
[3] Engineering Thermodynamics by Moran and Shapiro
[4] Engineering Heat Transfer by J P Holman
[5] Fundamentals of Heat and Mass Transfer, Incropera, P.P. and Dewitt, D.P.
[6] Heat Transfer by Frank Krieth

Course code	Course Name	L-T-P	Credit
SSE504	Vacuum Science & Thin Film Technology	3-0-0	6

Content:

Behavior of Gases; Gas Transport Phenomenon, Viscous, molecular and transition flow regimes,

Measurement of Pressure, Residual Gas Analyses; Production of Vacuum - Mechanical

Pumps(rotary, turbo molecular pumps), Diffusion pump, Getter and Ion pumps, Cryopumps, Materials in Vacuum; High Vacuum, and Ultra High Vacuum Systems; Leak Detection.

Physical Vapor Deposition – Hertz Knudsen equation; mass evaporation rate; Knudsen cell, Directional distribution of evaporating species Evaporation of elements, compounds, alloys, Raoult's law; e-beam, pulsed laser and ion beam evaporation, reactive evaporation, Glow Discharge and Plasma, Sputtering–mechanisms and yield, dc and rf sputtering, Bias sputtering, magnetically enhanced sputtering systems, reactive sputtering,

Chemical Vapor Deposition - reaction chemistry and thermodynamics of CVD; Thermal CVD, plasma enhanced CVD for amorphous silicon thin films,

Other Chemical Techniques - Spray Pyrolysis, Electrodeposition, Sol-Gel technique, Nucleation &

Growth: capillarity theory, atomistic and kinetic models of nucleation, basic modes of thin film growth, stages of film growth & mechanisms,

Epitaxy–homo, hetero and coherent epilayers, lattice misfit and imperfections, epitaxy of compound semiconductors, scope and applications of thin films in solar cells

Books & References:

[1] Milton Ohring, Materials Science of Thin Films, Second Edition

[2] James M. Lafferty, Foundations of Vacuum Science and Technology

[3] J.F. O'Hanlon, A User's Guide to Vacuum Science and Technology

[4] Rao, Ghosh and Chopra, Vacuum Science and Technology

Course code	Course Name	L-T-P	Credit
SSE505	**Renewable Energy & Energy Management**	**3-0-0**	**6**

Content:

Solar energy: Devices for thermal collection, solar energy applications

Wind energy: analysis of wind speeds, different types of wind turbines, Wind date, factors for site selection, performance characteristics
Bio Energy: Biomass gasifiers, types, design and construction of biogas plants, scope and future

Tidal, wave and ocean thermal energy conversion plants, geothermal plants

Energy Management: Its importance, Steam Systems: Boiler efficiency testing, excess air control, Steam distribution, condensate recovery, flash steam utilization, Thermal Insulation Energy conservation in Pumps, Fans, Compressed Air Systems, Refrigeration & Air conditioning systems

Waste heat recovery: Recuperators, heat pipes, heat pumps, Cogeneration - concept, options (steam/gas turbines/diesel engine based), selection criteria, control strategy

Heat exchanger networking: concept of pinch, target setting, problem table approach, composite curves. Demand side management, financing energy conservation

Books & References:

[1] Solar Energy by S P Sukhatme and J K Nayak
[2] Solar Engineering of Thermal Processes by Duffie and Backman

[3] Energy Management and Conservation Frank Kreith and D Yogi Goswami Handbook CRC press
[4] TERI hand book on Energy Conservation
[5] Industrial Energy Conservation Manuals, MIT Press
[6] Heat Exchanger Network Synthesis- Process Optimisation by Energy and Resource Analysis by Uday V Shenoy, Gulf Publ. Company

Course code	Course Name	L-T-P	Credit
SSE506	Laboratory work/ Energy Lab-1	0-0-4	2

Content:

1. Techniques of thin film depositions.
2. Basics of solar collector constructions and characterizations.
3. Solar PV systems lab

Course code	Course Name	L-T-P	Credit
SSE511	Photovoltaic Science & Engineering	3-0-0	6

Content:

Properties of sunlight
Semiconductor properties such as absorption, generation, recombination, etc., p-n junctions and device physics
Theoretical limits of photovoltaic conversion
Solar cell operation, efficiency limits, losses and measurement
Silicon solar cell technology (thin-film and wafer-based)
Design of silicon solar cells
High-efficiency III-V multi-junction solar cells
Other materials and device structures
Modules and arrays, simple photovoltaic systems
Economic analysis and environmental aspects of photovoltaic systems
PV in Architecture (BIPV)
Financing PV Growth

Books & References:

[1] Solar cells: operating principles, technology and system applications by Martin A. Green

[2] Physics of Solar Cells by Peter Wurfel

Course code	Course Name	L-T-P	Credit
SSE512	**Solar Thermal Engineering**	**3-0-0**	**6**

Content:

Solar Radiation: Extra terrestrial and terrestrial radiations, instruments to measure solar radiation, solar radiation geometry, empirical correlation for predicting available solar radiation, computation of solar radiation on horizontal and tilted surfaces

Solar flat plate collectors: Construction, performance analysis, estimation of losses, collector efficiency and collector heat removal factor, testing procedures

Solar Air Heaters: Performance analysis of Conventional Air heater, testing procedures

Concentrating collectors: Flat plate collector with booster mirror, cylindrical parabolic collectors, compound parabolic collector, paraboloid dish collector, central receiver collector

Thermal Energy Storages: sensible, latent and thermo-chemical storage

Solar process load: Hot water load, space heating load, building loss coefficient, cooling load, swimming pool heating load

Solar water heating: Freezing, boiling and scaling, natural and forced circulation systems, integral collector storage systems, water heating in space heating and cooling, testing and rating of solar water heater, economics of solar water heating

Building heating (Active): Different types of systems, Parametric study, solar energy heat pump systems, solar system over heating, solar heating economics

Building heating (Passive and Hybrid Methods): Concept of passive heating, comfort criteria and heating load, movable insulation, shading, direct heat gain systems, hybrid systems, economics of passive heating

Solar cooling: Solar absorption cooling, combined heating and cooling, simulation study of solar air conditioning, solar desiccant cooling,

Solar Pond: working principle, performance analysis, experimental studies, operational problems

Solar Industrial process heat: integration with industrial design, mechanical design consideration, different types of system, economics of industrial process heat

Books & References:

[1] Solar Engineering of Thermal Processes by Duffie and Backman
[2] Solar Energy by S P Sukhatme and J K Nayak

Course code	Course Name	L-T-P	Credit
SSE513	Semiconductor Processing & Characterization	3-0-0	6

Content:

Semiconductor Processing Technology

- Crystal growth
- High-temperature processing & implantation: diffusion, ion implantation, oxidation, Rapid Thermal Processing (RTP)
- Lithography: Optical and non-optical
- Vacuum science and plasma
- Etching: Wet etching, Chemical Mechanical Polishing (CMP), plasma etching, ion milling
- Thin film deposition: electron beam deposition, sputtering, Chemical Vapour Deposition (CVD), epitaxial growth
- Silicon, CMOS, GaAs, MEMS, IC technologies

Semiconductor Material and Device Characterization

- Electrical characterization: resistivity, carrier doping and density, contact resistance and Schottky barriers, mobility, carrier lifetime, oxide and interface trapped charges
- Optical characterization: microscopy, ellipsometry, X-ray diffraction, photoluminescence, Raman spectroscopy, Fourier Transform Infrared Spectroscopy (FTIR)
- Chemical and Physical characterization: Scanning Electron Microscopy (SEM), Auger Electron Spectroscopy (AES), Transmission Electron Microscopy (TEM), Electron Beam Induced Current (EBIC), Secondary Ion Mass Spectrometry (SIMS)
- Solar cell topics: current-voltage, series and shunt resistance, internal and

external quantum efficiency,

Books & References:

[1] The science and engineering of microelectronic technology by Stephen A. Campbell

[2] Semiconductor Material and Device Characterization by Dieter K. Schroder

Course code	Course Name	L-T-P	Credit
SSE514	**Modeling & Simulation**	**3-0-0**	**6**

Content:

Describing physical systems through models; defining model of system relevant to the problem being addressed. Physical theories as models - forming the basis of the scientific method; law of parsimony (Occam's razor). Role of modeling and simulation in engineering. Importance of model validation; use in analysis and design; *what if* questions; successive refinement of model. Examples.

Basic concepts. Dimensional analysis, scaling, conservation laws and balance principles. Linearity; piece-wise linear approximations. Deterministic *versus* probabilistic models. Examples.

Simulation of mathematical model using computer software; introduction to Matlab and PSpice using simple models. Importance and types of graphical output.

Basic numerical techniques: matrix operations, integration, solution of differential equations. Types of error; convergence and stability.

Case studies in modeling: Models of mechanical systems, fluid behavior, heat transfer, RLC circuits, diode, and solar photovoltaic cell; transient and steady-state response; forced response; effects of non-linearity. Stress will be on (i) defining the model based on understanding of system behavior, and (ii) simulation of the model using Matlab and other software, under varying conditions

[Lab exercises to be included in laboratory course]

Books & References:

[1] Clive L. Dym, *Principles of Mathematical Modeling*, Elsevier, Indian edition (2004).

[2] C. Ray Wylie and Louis C. Barrett, *Advanced Engineering Mathematics*, McGraw-Hill International Student Edition

[3] Kendall Atkinson and Weimin Han, *Elementary Numerical Analysis*, Wiley Student Edition (2006).

[4] Edward A. Bender, *An Introduction to Mathematical Modeling*, Dover Publications (2000).

[5] Walter J. Meyer, *Concepts of Mathematical Modeling*, Dover Publications (2004).

[6] Rutherform Aris, *Mathematical Modeling Techniques*, Dover Publications (1994).

[7] Reinhard Illner, C. Sean Bohun, Samantha McCollum, Thea van Roode, *Mathematical Modelling: A Case Studies Approach*. American Mathematical Society (2005)

Course code	Course Name	L-T-P	Credit
SSE517	**Laboratory Work/Energy Lab-2**	**0-0-4**	**2**

Content:

1. Vacuum techniques of solar cell fabrication
2. Techniques of solar cell characterizations
3. Techniques of solar thermal collectors
4. Modeling and simulation lab

Elective courses (on offer) **Outline:**

Elective: Advanced Solar Cells

Course contents:

Black body fundamentals; Energy, entropy and efficiency; Limits in single junction solar cells; Tandem cells; Hot carrier cells; Multiple electron-hole pairs per photon; Impurity photovoltaics and multiband cells; Thermophotovoltaics and thermophotonic conversion; Nano-structured Solar Cells

Books & References:

[1] Third Generation Photovoltaics: Advanced Solar Energy Conversion by Martin A. Green.
[2] Photovoltaic Materials by Richard P. Bube
[3] Nano Structured Solar Cells by Tesuo Soga

Elective: Optimization Techniques

Course contents:

Introduction: Formulation of the optimization problem, Different optimization methods. Unconstrained optimization: Introduction, Structure of Methods, Newtonlike Methods, Conjugate Direction Methods, Restricted Step Methods, Sums of Squares and Nonlinear Equations. Constrained optimization: Introduction, Linear Programming, The Theoryof Constrained Optimization, Quadratic Problems, General Linearly Constrained Optimization, Nonlinear Programming, Integer Geometric and network programming, Non-Smooth Optimization. Calculus of Variations (Optional): Euler-Lagrange Equations, special cases and extensions, Important Physical Examples.

Books & References:

[1] J.Luenberger D.G. Introduction to Linear and Nonlinear Programming, 2nd edition, Addison Wesley, 1984.
[2] Fletcher. R : Practical methods of Optimization ohn Wiley, 1980.
[3] C. H. Papadimitriou, K. Steiglitz, Combinatorial Optimization: Algorithms and Complexity, Dover books 1998.
[4] William H. Press, Brian P. Flannery, Saul A. Teukolsky, andWilliam T. Vetterling, Numerical Recipes in C: The Art of Scientific Computing. Cambridge University Press.
[5] KF Riley, MP Hobson, SJ Bence,Mathematical Methods for Physics and Engineering 3rd ed., Cambridge 2006.
[6] Arfken and Weber, Mathematical Methods for Physicists 6th ed. Elsevier (2005).