**Course Description:** This course is designed for first year graduate and senior undergraduate students from engineering disciplines and is intended to educate students in the design and applications of solar energy engineering. It will focus on fundamentals of solar energy conversion, photovoltaic and photothermal engineering, optical systems, photoelectrochemical cells for hydrogen generation, and energy storage and distribution systems. The course covers solar energy insolation and global energy needs, current trends in solar plants, thin film solar cells, and solar cell material science. Design and installation of solar panels for residential and industrial applications and connections to the national grid and cost analysis will be discussed. In addition, basic manufacturing processes for the production of solar panels, environmental impacts, and the related system engineering aspects will be included to provide a comprehensive state-of-the-art approach to solar energy utilization.

**Course Goals:**

1. Learn the fundamentals of solar energy conversion systems, available solar energy and the local and national needs, photovoltaic and photothermal engineering applications, emerging technologies,
2. Understand the interdisciplinary approach for designing stand-alone PV systems, predicting performance with different systems, Implementing design with cost analysis,
3. Gain system engineering expertise related to photovoltaic energy conversion: generation, storage, and grid connection processes for residential and industrial applications, and
4. Be able to advance the current technology of the solar energy systems for making the process economical, environmentally safe and sustainable. Be able to serve industries or academia involved in sustainable energy engineering.

**Course Outcomes:** As an outcome of completing this course, the students will:

1. Gain an understanding of the available solar energy and the current solar energy conversion and utilization processes,
2. Have a working knowledge of semiconductor physics, optical systems, load matching, and storage and grid connections related to photovoltaic engineering,
3. Be able to comprehend the challenges in sustainable energy processes, perform cost analysis, design photovoltaic systems for different applications meeting residential and industrial needs, predict and test performance, and
4. Understand the manufacturing processes involved, environmental challenges that need to be solved, economic aspects, and future potentials of solar energy utilization.

**Text books:**

1) Solar Cells: Operating Principles, Technology and System Applications, Martin Green Published by the University of New South Wales, 1980 (Required) available at the BU Barnes and Noble book store
3) www.pveducation.org

References:
2) Thin film Solar Cells, Jeff Poortmans and Vladimir Arkhipov (Ed) John Wiley and Sons Ltd. 2006
4) Solar Electricity, Second Edition, Thomas Markvart (Editor), John Wiley and Sons, Ltd., 2000,

Grading:
1) Homework/Quiz (8) 20%
2) Midterm Exams (3) 45%
3) Class Project (1) 20%
4) Final Exam 15%

Class Hours: Mon, Wed; 12:00 noon to 2:00 pm, Room EMB 105, 15 St. Mary’s Street, Boston
Office Hours: Wednesdays: 3:00 pm to 6:00 pm. Room PHO 532
Teaching Assistant: John Hudelson jnhudel@bu.edu.

DL Students: Students registered in the distance Learning (DL) section, would be able to participate in the class in real time when the students are listening to the lectures during the class ours. All students are encouraged to contact the Professor or the Teaching Assistant by email.

Spring 2014 Schedules

Lecture 1. (January 15)
Course outline, resources, and requirements
Solar energy, the sun, Available solar energy from the sun, insolation vs. world energy demand, Blackbody radiation, Planck’s Radiation Law, Wien’s displacement Law, Stefan Boltzmann Equation, spectral distribution of extraterrestrial and terrestrial radiations, solar constant, properties of solar radiation

Lecture 2 (January 22)
Sun-Earth Geometry: Motion of the earth relative to the sun, Apparent motion of the sun relative to a fixed observer on the earth, Air Mass, estimation of available solar radiation on earth, absorption of solar radiation by earth’s atmosphere, direct, diffused and albedo components of sunlight, solar radiation table, global radiation data.

Lecture 3 (January 27)
Mean annual irradiance on horizontal surface across the world, Effects of latitude, declination, slope, surface azimuth angle, hour angle, and the angle of incidence. Radiation on an inclined surface: direct, reflected, and diffused radiations, radiation on inclined
surfaces, calculation of angles of incidence, direction of beam radiation, angles for tracking surfaces, ratio of beam radiation on tilted surface to that of horizontal surface

Lecture 4 (January 29)
Introduction to PV, conversion of solar radiation to electrical energy, PV sizing for meeting the world’s energy need, how much land area is needed, advantages and disadvantages of PV systems. Reliability and sizing of the PV/PT systems, uncertainty and risk factors in PV/PT design, Cost analysis, Terawatt challenge, Energy payback, different options of PV modules, thin film solar cells.

Lecture 5 (February 3)
Review of semiconductor properties, Introduction to crystal structures, Energy bands, Energy band structures, Fermi Dirac distribution functions, Dynamics of electrons and holes in a crystal, Energy density of allowed states, Densities of electrons and holes, Bond model of Group IV semiconductors, Fermi level.

Midterm Exam 1 (Take Home Test: given February 3; due February 8)

Lecture 6 (February 5)
Equilibrium carrier concentrations, Location of Fermi level in doped semiconductors, Donors and acceptors, Effect of impurities, Charge carrier transport, Drift and diffusion currents, Mobility of electrons and holes, Effects of temperature and doping (including impurities) on charge carrier mobility.

Lecture 7 (February 10)
Light absorption, Direct-bandgap and indirect bandgap semiconductors, light absorption coefficient, Reflection and reflection losses, Absorption as a function of photon energy, Carrier transport.

Lecture 8 (February 12)
Carrier recombination, Surface states and trap states, Auger, radiative, traps-assisted, and surface recombination processes, Densities of ionized donors and acceptors, Nondegenerate conditions.

Lecture 9 (February 20)
Review of crystalline solar cells for Midterm Exam 2

Midterm Exam 2 (February 24)

Lecture 10 (February 26)
Basic equations of semiconductor devices, continuity equation, Current density equations, pn-junctions, Electrostatics of pn junctions, space charge regions, depletion regions, built-in voltage, diffusive flow of charge carriers in quasi-neutral region,

Lecture 11 (March 3)
Poisson’s equations, electrical field strength and potential distributions, Junction capacitance. Carrier injections, Minority carrier concentrations in the quasi neutral region, Minority carrier currents, Dark and illuminated characteristics
Lecture 12 (March 5)
Fundamental principles of solar cell operation, Solar cell device physics, Basic structure of solar cells, Quasi Fermi energy levels, Law of junctions, Carrier generation rate, Recombination rate, Dark current, Light generated current, Current-voltage (I-V) relationship.

Lecture 13 (March 17)
Solar cell output parameter, Fill factor, solar cell efficiency, Short circuit current, Open circuit voltage, Maximum power point operation, Effect of finite width of the solar cell, Solar cell equivalent circuit, Effect of bandgap, maximum thermodynamic efficiency.

Lecture 14 (March 24)
Practical efficiency limit, Losses in short circuit current, open circuit voltage, efficiency, Temperature effects, Fill factor losses, I-V characteristic measurement, Efficiency measurement, Parasitic resistances, Effects of series and shunt resistances

Lecture 15 (March 26)
Silicon solar cells to Photovoltaic Module (PV) production, Cell fabrication and interconnections, Top and Bottom connections, Manufacturing process, Cell matrix, encapsulation, vacuum lamination, Post-lamination steps, Bifacial modules, Electrical and optical performance of modules, Local shading and hot spot formation, Field performance.

Lecture 16 (March 31)

Lecture 17 (April 2)
Solar grade Silicon production, Quartz to metallurgical-grade (MG) silicon, MG silicon to semiconductor grade (SG) polysilicon, SG polysilicon to single-crystal ingot by Czochralski process, Ingot to silicon wafers, wafering processes, Requirements of monocry stalline solar (c-Si) cells, microworystalline silicon (mc-Si) solar cells production by block-cast sheet production method, comparison between Cz-Si solar cells and mc-Si solar cells.

Lecture 18 (April 3)
Inverters (DC/DC, DC/AC), Power conditioning, maximum power point operation, stand-alone PV system design, Grid-connected PV system, Balance of System (BOS) for PV module installation, Concentrated Solar Power (CSP) systems.

Midterm Exam 3 (April 7)

Lecture 19 (April 9)
Thin film solar cells, Amorphous silicon (a-Si) solar cells, Cadmium Telluride (Cd-Te) Solar cells, Cu(InGa)Se₂ solar cells, Dye-sensitized solar cells, Organic and polymer solar cells.

Lecture 20 (April 14)
Measurements and characterization of solar cells and PV modules, V – I characteristics, spectral response measurements, measurements and characterization of thin film solar cells.
Lecture 21 (April 16)
Domestic, industrial and commercial applications, Lifetime of the PV modules, Degradation caused by UV radiation, Moisture penetration, Corrosion, Dust deposition/soiling losses, Reflection losses, Thermal effects, Delamination of the module, prevention of energy yield losses.

Review for Final Exam (April 24)

Class Project Presentations 2 (April 28)

Class Project Presentations (April 30)

Final Exam (May 7)
To be announced

Course Policies:

1. Missed Exam – Absence from an exam can be excused only for reasons of illness, or an unavoidable reason. In each case, permission of the instructor is required, as well as a written authorization by a physician (in the case of illness) or other appropriate authorized signature. The student will be required to take a makeup exam.

2. Late Homework – Late homework will be accepted until the date when the solutions are posted on the Blackboard. A penalty of 5% off per day after the due date may be applied. A weekend counts as a single day.

4. Attendance and participation in the class are considered essential and required.

5. Exams given in class periods are closed book and closed note tests. However, students can bring one page (both sided) notes.

6. All students are required to follow honor code.