**BU Electrical and Computer Engineering ECE) Department and Material Science and Engineering (MSE) Division**

# EC/MS 573 Solar Energy Systems (2021): Syllabus

**Instructor: Malay Mazumder**

## Textbooks (required) and recommended books for reference

1. Solar Energy, The Physics and Engineering of Photovoltaic conversion technologies and systems, UIT Cambridge, England. 2015 (required)

2. www.pveducation.org, by C. Honsberg and S. Bowden, Arizona State University, 2019 (online) (required)

## References

1. Solar Cells: Operating Principles, Technology and System Applications, Martin Green Published by the University of New South Wales, 1980,

2. Photovoltaic Solar Energy: From Fundamentals to Applications, Angele Reinders, Pierre Verlinden, Wilfried van Stark, and Alexandre Freundlich, Wiley, 2017

3.Photovoltaics: Fundamentals, Technology and Practice. Konrad Mertens, Second Edition, Wiley, 2019

## 2020-2021 Catalog

**Course Description:** This course aims to provide fundamental and contemporary knowledge in solar energy systems in the context of recent advances in renewable energy processes, providing fundamental understandings and engineering applications in the areas of: Solar energy conversion processes, solar resources, semiconductor physics related to solar cell operation, direct and indirect band gaps, absorption of solar radiation, charge carrier generation and recombination, carrier transport, p-n junctions, silicon solar cell devices and structures, current-voltage (I-V) characteristics, diode characteristics, diffusion and drift currents, energy conversion efficiency and limitations, multi-junction solar cells, photovoltaic (PV) module assembly and performance analysis, maximum power point operation, stand-alone and grid-connected PV systems, energy storage, levelized cost of electricity, environmental benefits and engineering challenges for meeting global energy demand.

A class research project is required to augment the basic science and engineering principles and economics of residential, commercial, and utility-scale PV applications. Students form team to research, write reports and give presentation on a topic of their choice related to the growth of solar energy technologies and manufacturing processes towards sustainable terawatt-scale application.

**Prerequisites:** No graduate courses are required as prerequisite. Suggested Courses: (1) ENG EK 408 and (2) ENG EC 471 or consent of the instructor before registering for the course.

The course is designed for the first-year graduate and senior undergraduate students from engineering and physical science disciplines. Interested students may contact the instructor about prerequisites.

**Status in the Curriculum:** Elective

**Course learning objectives:**

**Students will be able to:**

1. Learn the fundamentals of solar energy conversion systems, solar resources for meeting global energy needs, Photon flux, spectral irradiance, radiant power density, Blackbody radiation, Planck's Radiation Law, Stefan Boltzmann Equation, extraterrestrial and terrestrial radiation, air mass, solar insolation.

2. Understand semiconductor materials and properties related to solar cell operation, energy band structures, Fermi Dirac distribution functions, intrinsic carrier concentration, doping, dynamics of electrons and holes in a silicon crystal, energy density of allowed states, location of Fermi level in intrinsic and doped semiconductors, donors and acceptors, effect of impurities,

3. Describe the light absorption process, charge carrier generation and recombination processes, direct and indirect band semiconductors, charge carrier transport, drift, and diffusion currents, doping process with donors and acceptors, mobility of electrons and holes,

4. Be familiar with the fundamental principles of p-n junction, p-n junction diodes, diode equation, solar cell architecture and operation, energy band diagrams, Fermi energy levels, band diagrams under forward and reverse bias, and dark current characteristics,

5. Comprehend silicon solar cells operation, electrical and optical properties, absorption depth, dark current and light generated current densities, lifetime of minority carriers, diffusion length, basics of charge separation, recombination processes in the p- and the n-sides, surface passivation of dangling bonds,

6. Draw current voltage (I-V) characteristics under dark and illuminated conditions, define built-in voltage under forward and reverse bias, solar cell output parameter, fill factor (FF), conversion efficiency, maximum power point operation, and determine the angle of incidence of sunlight as functions of the latitude and longitude of the location, azimuth and tilt angles and the solar time,

7. Describe optical losses, anti-reflection coating, surface texturing, light trapping, practical efficiency limit, losses in short circuit current, losses in open circuit voltage, efficiency, temperature effects, fill factor losses, effects of series and shunt resistances, top contact design, back surface field, effects of minority carrier diffusion length, solar cell architecture, methods of optimization to improve conversion efficiency,

8. Understand methods of measurements of solar cell parameters, solar irradiance, spectral analysis, current–voltage characteristics, quantum efficiency vs. wavelength of illumination, effects of angle of incidence (tilt angle and azimuth angles), effects of direct and diffused radiation, effects of latitude and longitude,

9. Gain knowledge in the manufacturing processes involved in the production of Photovoltaic (PV) modules, solar cell interconnections, top and bottom connections, basic manufacturing process, cell matrix, encapsulation, vacuum lamination, electrical and optical performance analysis, and losses due to environmental factors, such as soiling of the optical surface of the PV modules,

10. Understand the role of power electronics, DC-to-DC, DC-to-AC conversion (string converters and micro-converters), and charge controllers for energy storage systems. Examine applications of Energy Storage systems including Li-ion batteries, super capacitors, grid-tied systems, and Hydro-pumping systems, design stand-alone PV systems for residential application, predict its performance and estimated the payback period,

11. Gain understanding of the current trends in thin film solar cells, including Cadmium Telluride (Cd-Te) Solar cells, $Cu(InGa)Se_2$ solar cells, Organic–inorganic Perovskite solar cells, transparent conducting oxide films used for charge carrier collection, and

12. Present the Class Research Project Report.

These outcomes will enhance students' knowledge of solar energy systems and their applications in the field of renewable energy engineering, ability to design solar PV systems, solve practical problems, evaluate the performance of solar installations, conduct laboratory experiments, and pursue research in advancing the PV technologies.

**Major Topics and Time spent (in weeks):**

- Solar Resources, solar-to-electrical and thermal energy conversions, potential for meeting global energy needs: (one and a half weeks)

- Semiconductor materials, interaction of light with semiconductors, generation and recombination of charge carriers, band gaps, valence band and conduction band, mobility of electrons and holes: (two weeks)

- Principles of solar cells operation, p-n junctions, effects of bias voltage on energy band diagram, solar cell parameters, electrons and hole separation, external and internal quantum efficiency: (two weeks)

- Losses and efficiency limits, design principles of solar cells, incident solar radiation (insolation) on solar cells, effects of latitude and longitude of the location, tilt, and azimuth angles of the front surface of the solar cells, atmospheric effects, and solar time on insolation (one and a half weeks)

- Fabrication of PV modules with series and parallel connections of solar cells, PV module parameters, module design to match the annual load based on the meteorological parameters, power output and performance analysis: (two weeks)

- Introductions to power electronics, DC-to-DC, DC-to-AC conversion (converters), and charge controllers for energy storage systems. Design of stand-alone and grid-connected PV systems and other energy storage systems (two weeks)

- Current advancements and prospects of growth of solar PV plants (one week)

**Status of Continuous Improvement Review of this Course:**
**Date Last Reviewed:** **Reviewed by**:

**Prepared by**: Malay Mazumder **Date**: November 30, 2020