ECE 414A/514A
Photovoltaic Solar Energy Systems

Instructor: Prof. Raymond K. Kostuk

Time: MWF 04:00 PM-04:50 PM

Classroom: Harvill 204

Office Hours: 4-5 PM TuTh ECE Rm. 556E or email for appointment

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Abstract:

The solar illumination reaching the surface of the earth provides 4×10^{23}J/year and is about $10^4\times$ the global annual energy consumption. The captivating feature of this energy source is that it is clean, renewable, and plentiful especially in the U.S. South West. The ability to harness this energy source has tremendous implications for the environment and global stability. During recent years there has been an upsurge in the interest, investment, and development of photovoltaic cells and it is expected to continue into the foreseeable future. This trend offers significant opportunity for researchers and engineers.

Course Content:

This course is intended to provide an introduction to the theory and operation of different types of photovoltaic devices, the characteristics of solar illumination, and the advantages and characteristics of concentrating and light management optics. The physical limits on photovoltaic cell performance and practical device operation will be analyzed. The main device emphasis will focus on different types of silicon photovoltaic cells including crystalline, amorphous, multi-crystalline, and thin film solar cells. An overview of other types of photovoltaic cells including multi-junction III-V, CdTe, $CuInSe_2$, and organics will also be given. A discussion of radiometric and spectral properties of solar illumination will be presented and the impact of these factors on solar cell design will be explored. Techniques for increasing the performance of solar cells by light trapping, photon recycling, and anti-reflection coatings will be covered. The design and operation of imaging and non-imaging concentrators will also be discussed. Basic experiments related to PV cell measurements and the optical properties of concentrators are also planned for the course.

Grading Policy:

Graduate Students:

20% Midterm Exam
25% Homework
10% Lab Experiments
10% System Design Project
35% Final Exam

Undergraduate Students:
10% Lab Experiments
20% Midterm Exam
15% Homework
10% Paper Review
10% System Design Project
35% Final Exam

- Graduate students will be assigned extra problems on exams and homework. Graduate and undergraduate averages will be computed separately.
- The student design project will consist of the design and evaluation of a photovoltaic electric power generation system.
- Both Graduate Undergraduate students will be graded on the homework and lab assignments.
- Graduate students will also be required to review a journal paper on new research in PV.

Text: Online Text at http://pvcdrom.pveducation.org/
Class Text: *Applied Photovoltaics 2nd Ed.*, S.R. Wenham, M. A. Green, M. E. Watt, and R. Corkish, Earthscan, ISBN-13 978-84407-401-3 (2007). (Not Required)
Recommended Texts: *The Physics of Solar Cells*, by Jenny Nelson, Imperial College Press, 2006; *Physics of Solar Cells,2nd Ed.*, Peter Wurfel, Wiley-VCH, ISBN: 978-3-527-40857-6 (2009).

Topics

1. Introduction
   a. Energy needs of the planet/US
   b. Energy available from solar radiation
   c. Greenhouse effect
   d. Different types of PV systems; examples from manufacturers; CdTe; CIGS; Si, a-Si, organic PV, concentrator systems:
   e. Basic properties of solar radiation – sun movement, AM1.5 spectrum
   f. Problems with PV energy systems – efficiency, intermittency, storage;
2. Economics and metrics of PV systems – (1 lecture last year)
   a. Cost of different energy sources (Ken Zweibel's paper)
   b. Cost per area
   c. $\$/W_p$
   d. Performance ratio
   e. Normalized performance metric (David King)
   f. Levelized cost of energy (LCOE); Feed in tariffs (FITs)
   - Energy payback time (EPBT)
   PROBLEMS
3. Radiometric properties of solar radiation (3 lectures)
   a. Spectral content of solar illumination
   b. Air mass conditions; solar constant
   c. Radiometric parameters – measuring illumination on a collector
   d. Black body characteristics
   e. Modeling the sun as a blackbody

PROBLEMS

4. PV cell operating characteristics (2 lectures)
    a. PV cell circuit equivalent – approach PV operation purely from a circuit perspective
    b. Ideal diode equation – computation of V_{oc}
    c. External loading of a PV cell
    d. V_{oc}, I_{sc}, I-V curves
    e. FF, MPP

    PROBLEMS
5. PV Cell Physics
    a. Direct and indirect energy band gap
    b. Light absorption; spectral dependence
    c. Optimum band gap – Shockley Quiesser limit
    d. PV diode model: space charge, QNR
    e. Minority carrier generation rates, lifetime, drift, diffusion lengths
    f. Recombination rates
    g. Semiconductor equations for PV cells
    h. Two-diode model related to V_{oc}, I_{sc};
    i. Effects of shunt and series resistance

    PROBLEMS
6. PV Cell Design
    a. Silicon cell construction
    b. Optical reflection, anti-reflection coatings, light trapping, texturing
    c. Electrical grid contacts
    d. Novel designs – nano-wire PV cells-reduced diffusion length
7. Modules and arrays
    a. Series and parallel connected cells
    b. Effects of shading on series and parallel connected cells – V_{oc} and I_{sc}
    c. Power dissipation in shaded cells
    d. Use of by-pass diodes; dissipation of power in by-pass diodes
    e. Basic inverter operation
    f. Grid-tie and battery connected installations

    PROBLEMS
8. System design issues (REVISE)
    a. Estimating available solar illumination
    b. Nominal operating cell temperature (NOCT)
    c. Estimating performance at non-STC
    d. System energy yield
    e. Performance with one-axis tracking

    PROBLEMS
9. Solar concentrators and concentrator systems (NEW)
    a. Optical concentrator design – limits based on radiance theorem; tracking requirements
    b. High concentration and low concentration systems
    c. Concentrator PV cell properties
    d. Multi-junction cells – high efficiency with multiple bandgaps

    e. Spectrum-splitting systems

    PROBLEMS

10. Testing and characterization Methods (NEW)
    a. I-V measurements; V_{oc}, I_{sc} measurement
    b. Sourcemeter operation – 4 wire connection
    c. Spectral measurements –spectrometers
    d. Test yard evaluations: energy yield, reliability, degradation testing

    PROBLEMS

11. Thin Film Materials (NEW)
    a. Amorphous silicon
    b. CIGS
    c. CdTe
    d. Light trapping techniques and structures
12. Storage Systems (NEW)
    a. Batteries: battery terminology; charging and discharge properties; different types of batteries; limits of battery systems
    b. Hydrogen production systems
    c. Compressed gas storage systems
13. Limits to solar energy conversion
    a. Thermal equilibrium considerations
    b. Carnot efficiency, Landsberg, and Black Body limit
14. Third generation systems and future prospects
    a. Plasmonic enhancement of PV cell energy yield
    b. Refinement of silicon processing
    c. Optical techniques to increase PV system energy yield