# Syllabus

## Important notes

1. Class will take place at the scheduled day & time and will occur synchronously via a Zoom meeting link to be posted on blackboard. Cameras must be turned on to encourage class participation.
2. Problem sets are still due at the start of class but should be deposited electronically in a shared google drive folder I will share with you via your stonybrook.edu email account.
3. Final exam will be given at the time determined by the registrar and will be given online with links to be shared on blackboard.
4. If you have a physical, psychological, medical or learning disability that may impact your course work, please contact the Student Accessibility Support Center, ECC (Educational Communications Center) Building, Room 128, (631)632-6748. They will determine with you what accommodations, if any, are necessary and appropriate. All information and documentation is confidential.
   https://www.stonybrook.edu/commcms/studentaffairs/sasc/facstaff/syllabus.php

## 1. Course Staff and Office Hours

Instructor: Prof. Matthew D. Eisaman
matthew.eisaman@stonybrook.edu
631-632-8421
Light Engineering, 145

Office Hours: Wednesdays and Fridays, 11:00am to 1:00pm, ONLINE via Zoom link to be shared on Blackboard
*Other hours by appointment*

TAs: Atreyo Mukherjee, atreyo.mukherjee@stonybrook.edu

*Office hours and locations may change. Please check Blackboard for most up-to-date information.*

## 2. Course Description

## Title: ESE 413/513 Introduction to Photovoltaics

Introduction to the basic concepts of photovoltaic solar energy conversion, including: 1. The solar resource in the context of global energy demand; 2. The operating principles and theoretical limits of photovoltaic devices; 3. Device fabrication, architecture, and primary challenges and practical limitations for the major technologies and materials used for photovoltaic devices. Students will gain knowledge of: the device physics of solar cells, the operating principles of the major commercial photovoltaic technologies, the current challenges and primary areas of research within the field of photovoltaics, and a basic understanding of the role of photovoltaics in the context of the global energy system.

**Pre/co-requisites:** ESE 231 (Introduction to Semiconductor Devices) or equivalent. The course assumes a basic understanding of semiconductor device physics, but critical elements to photovoltaic devices will be reviewed in this course.

**Credits:** 3

## 3. Textbook

**REQUIRED TEXTBOOKS**

J. Nelson, *Physics of Solar Cells*, Imperial College Press, 2003. ISBN-13: 978-1860943492.

**OPTIONAL TEXTBOOKS**

C. Honsberg and S. Bowden, Photovoltaics: Devices, Systems and Applications CDROM. (http://www.pveducation.org/pvcdrom)

K. McIntosh, M. Abbott, and S. Baker-Finch, PV Lighthouse (http://www.pvlighthouse.com.au/)
*Sunshot Vision Study*, Feb. 2012, US Dept. of Energy, Office of Energy Efficiency and Renewable Energy (EERE).

**SELECTED READINGS MADE AVAILABLE ON BLACKBOARD**

***Book Chapters***

A. Luque and S. Hegedus, eds., *Handbook of Photovoltaic Science and Engineering, 2nd Edition*, John Wiley & Sons, Inc., 2011, ISBN: 978-0-470-72169-8.

Gavin J. Conibeer and Arthur Willoughby, eds., *Solar Cell Materials: Developing Technologies*, John Wiley & Sons, Inc., 2014, ISBN: 978-0-470-06551-8.

J. Poortmans and V. Arkhipov, eds., *Thin Film Solar Cells: Fabrication, Characterization, and Applications*, John Wiley & Sons, Ltd., 2006,

D. Abou-Ras, T. Kirchartz, and U. Rau, eds., *Advanced Characterization Techniques for Thin Film Solar Cells*, Wiley-VCH Verlag GmbH & Co., 2011. ISBN: 9783527636280.

L. Tsakalakos, *Nanotechnology for Photovoltaics*, CRC Press, 2010, ISBN-13: 978-1420076745.

A. Rockett, *The Materials Science of Semiconductors*, Springer, 2008, ISBN 978-0-387-68650-9.

*Primary literature*

V. Fthenakis, *Sustainability of photovoltaics: The case for thin-film solar cells*, Renewable and Sustainable Energy Reviews 13, 2746–2750 (2009).

W. Shockley and H. J. Quiesser, *Detailed Balance Limit of Efficiency of pn Junction Solar Cells*, Journal of Applied Physics 32, 510 (1961).

**ADDITIONAL RESOURCES (NOT REQUIRED):**

***Books***

M. Green, *Solar Cells: Operating Principles Technology (The Red Book)*, UNSW Photovoltaics, 1986. ISBN: 0858235803.

P. Wurfel. Physics of Solar Cells: From Basic Principles to Advanced Concepts. Wiley VCH, 2009. ISBN: 9783527408573.

***Periodicals and websites with up-to-date PV industry information***

Greentech media: http://www.greentechmedia.com/channel/solar
News, research, and analysis in the business-to-business solar market

Solar Industry Magazine: http://www.solarindustrymag.com/
Analyzes the details that help professionals navigate the solar market

Solar Power World: http://www.solarpowerworldonline.com/
For executives, managers, engineers, installers and technical professionals involved in the design, manufacturing, development, and installation of solar power projects

Photon International: http://www.photon.info/photon_home_en.photon Photovoltaic research and development, economy, new projects

PV Magazine: http://www.pv-magazine.com/. Latest technological trends and market developments worldwide

Many others: http://www.pvresources.com/Periodicals/English.aspx

## 4. Course Learning Objectives

At the end of this course, students will:

1. Know how to calculate the available solar energy resource at various global locations for specific photovoltaic installations
2. Understand semiconductor physics relevant to photovoltaic devices
3. Understand the major commercial and developing technologies for solar cells
4. Understand advanced characterization techniques for solar cells
5. Understand the economic and environmental issues relevant to photovoltaic systems, and know how to calculate the cost, environmental impact, and energy payback time of a photovoltaic system.

## 5. Student Learning Outcomes

| | Student Outcomes | % contribution |
|---|---|---|
| **1** | an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics. | 70% |

| | | |
|---|---|---|
| **3** | an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors. | 10% |
| **3** | an ability to communicate effectively with a range of audiences. | |
| **4** | an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgements, which must consider the impact of engineering solutions in global, economic, environmental, and societal contexts. | 10% |
| **5** | an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives. | |
| **6** | an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions. | |
| **7** | an ability to acquire and apply new knowledge as needed, using appropriate learning strategies. | 10% |

## 6. Schedule

Lectures : M, 6:05pm-8:55pm, Online via Zoom meeting link to be shared on blackboard

Mid-term exams will be given 1.5 hrs. online during the second lecture period of Week 7. The final examination will be 3 hrs. online with date and time TBD.

| Wk. | Date | Topics | Text: **Required** (Optional) BB = on Blackboard |
|---|---|---|---|
| 1 | 2/1 | 1. What is a photovoltaic (PV) device?<br>2. Why solar? PV in the context of global energy demand and climate change;<br>3. History of PV development and deployment<br>4. Overview of PV technologies<br><br>The solar resource: Spectra, insolation, diffuse vs. direct, atmospheric absorption (AM0 and. AM1.5), metrics for specifying system output, land area requirements | **Nelson 1,2**<br>**Honsberg 1,2**<br>**Sunshot Vision Study, Executive Summary and Ch. 1 (BB)**<br>**Sunshot 2030 Goals White Paper (BB)**<br>(Green 1) |
| 2 | 2/8 | Review of semiconductor physics | **Nelson 3**<br>**Honsberg 3.1**<br>(Green 2) |
| 3 | 2/15 | Semiconductor equations, light absorption and charge generation, recombination | **Nelson 4**<br>Honsberg 3.2-3.4<br>(Green 3) |
| 4 | 2/22 | Analysis of pn junctions, depletion approximation, solution of semiconductor equations in depletion approximation, derivation of ideal diode law, solar cell performance output parameters | **Nelson 5,6**<br>**Honsberg 3.5-3.6, 4.1-4.2**<br>(Green 4) |

| | | | |
|---|---|---|---|
| 5 | 3/1 | Ideal efficiency limits, Practical sources of loss, equivalent circuit model, characterizing solar cell performance | **Honsberg 4.2-4.4, 8 Nelson 10.1-10.3, Review Nelson 2** (Green 5) |
| 6 | 3/8 | First half of class: Improving efficiency by reducing optical losses: texturing, anti-reflection coatings, light trapping, photon recycling, concentrating PV (CPV) Second half of class: Improving efficiency by reducing optical losses (cont'd) | **Nelson 9 Honsberg 5.1** (Green 8.7-8.9) |
| 7 | 3/15 | First half of class: **MIDTERM** Second half of class: Improving efficiency by reducing electrical losses, Reducing recombination and resistance via doping profiles and top contact design | **Honsberg 5.2-5.4** (Green 8.1-8.6) |
| 8 | 3/22 | 1. Overview of commercial technologies 2. Commercial Technologies 1, Crystalline Si (c-Si). | **Same as week 7 Honsberg 5.2-5.4** (Green 8.1-8.6) **Week 8 Nelson 7 Honsberg 6,7 Luque 7 (BB)** |
| 9 | 3/29 | 1. Commercial Technologies 1, Crystalline Si (c-Si) continued. | **Same as Week 8 Nelson 7 Honsberg 6,7 Luque 7 (BB)** |
| 10 | 4/5 | 2. Commercial Technologies 2, Thin film Si (amorphous and crystalline) | **Nelson 8.1-8.5 Luque 11,12 (BB)** |
| 11 | 4/12 | Commercial Technologies 3: CdTe and CIGS | **Nelson 8.6-8.9 Luque 13,14 (BB)** |
| 12 | 4/19 | Emerging Technologies: organic PV (OPV) perovskites, CZTS | **Emerging Technologies Luque 16 (BB)** |
| 13 | 4/26 | Breaking the single-junction limit – multijunction cells and hot carriers, multiple exciton generation<br><br>Measurement and characterization of solar cells | **Breaking single-junction limit Nelson 10 Luque 8 (BB)**<br><br>**Characterization Honsberg 8 Selections from Abou-Ras (BB)** |
| 14 | 5/3 | 1. Economics of PV; Environmental impact and benefit of PV: Life cycle analysis, energy pay back timing, resource extraction and limitations<br><br>2. Review of important concepts for final exam | **SunShot Vision Study (2011) (BB) Fthenakis Lifecycle Chapter (BB) Fthenakis (2009) (BB) NY Times article (BB)** |
| | **TBD** | **FINAL EXAM** | **All topics** |

## 7. Assignments

*Problem sets*

There will be weekly problem sets. Problem sets will be distributed at the end of each lecture and will be **due the following lecture at the start of class**. Late problem sets **will not be accepted - no exceptions**. Please turn in what you have at the start of class. You must submit the problem set by depositing an electronic copy in the shared google drive folder I will share with you on Blackboard.

*Exams*

The midterm exam will be based on all information presented up through Week 6 and will be designed to take 1.5 hours. The final exam will include all material presented in all lectures and will be designed to take 3 hours. The final exam will be given online.

## 7. Grading

The course grade will be based on the following components:

| Item | Percent |
|---|---|
| **Problem Sets** | 50 |
| **Midterm exam** | 20 |
| **Final exam** | 30 |

Grades are based on the following scale:

A = 93-100, A- = 90-92
B+ = 88-89, B = 83-87, B- = 80-82
C+ = 78-79, C = 73-77, C- = 70-72
D+ = 68-69, D = 63-67, F <63

***Grading Policy for grad and undergrad versions are different. Midterm, final, and problem sets will contain more challenging questions that are required for graduate students but are optional (bonus points) for undergrads.***

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**Class Protocol**

All electronic devices are to be turned off during class unless advance permission is given by the instructor. No recording of lectures of any kind (including audio and video) is allowed. For online classes, cameras must be turned on to encourage class participation.

**Class resources**

Blackboard (http://blackboard.stonybrook.edu) will be used as the primary means of distribution for readings from the primary literature and submission of assignments.

If you have a physical, psychological, medical or learning disability that may impact your course work, please contact the Student Accessibility Support Center, ECC (Educational

Communications Center) Building, Room 128, (631)632-6748. They will determine with you what accommodations, if any, are necessary and appropriate. All information and documentation is confidential. https://www.stonybrook.edu/commcms/studentaffairs/sasc/facstaff/syllabus.php

Students who require assistance during emergency evacuation are encouraged to discuss their needs with their professors and Disability Support Services. For procedures and information go to the following website: http://www.stonybrook.edu/ehs/fire/disabilities ]

Each student must pursue his or her academic goals honestly and be personally accountable for all submitted work. Representing another person's work as your own is always wrong. Faculty are required to report any suspected instances of academic dishonesty to the Academic Judiciary. Faculty in the Health Sciences Center (School of Health Technology & Management, Nursing, Social Welfare, Dental Medicine) and School of Medicine are required to follow their school-specific procedures. For more comprehensive information on academic integrity, including categories of academic dishonesty, please refer to the academic judiciary website at http://www.stonybrook.edu/uaa/academicjudiciary/

Stony Brook University expects students to respect the rights, privileges, and property of other people. Faculty are required to report to the Office of Judicial Affairs any disruptive behavior that interrupts their ability to teach, compromises the safety of the learning environment, or inhibits students' ability to learn. Faculty in the HSC Schools and the School of Medicine are required to follow their school-specific procedures.

**Academic Honesty**

Any academic dishonesty on a written homework or lab will result in a zero grade for the assignment for all parties involved.

All exam work must be entirely your own with no collaboration or outside materials/information. Any academic dishonesty on the midterm exams or the final exam will result in failing the course. The case will be submitted to the College of Engineering's Committee on Academic Standing and Appeals.

**Electronic Communication Statement**

Email and especially email sent via Blackboard (http://blackboard.stonybrook.edu) is one of the ways the faculty officially communicates with you for this course. It is your responsibility to make sure that you read your email in your official University email account. For most students that is Google Apps for Education (http://www.stonybrook.edu/mycloud), but you may verify your official Electronic Post Office (EPO) address at http://it.stonybrook.edu/help/kb/checking-or-changing-your-mail-forwarding-address-in-the-epo.

If you choose to forward your official University email to another off-campus account, faculty are not responsible for any undeliverable messages to your alternative personal accounts. You can set up Google Mail forwarding using these DoIT-provided instructions found at http://it.stonybrook.edu/help/kb/setting-up-mail-forwarding-in-google-mail.

If you need technical assistance, please contact Client Support at (631) 632-9800 or supportteam@stonybrook.edu.

**Student Accessibility Support Statement**
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**Critical Incident Management Statement**
Stony Brook University expects students to respect the rights, privileges, and property of other people. Faculty are required to report to the Office of University Community Standards any disruptive behavior that interrupts their ability to teach, compromises the safety of the learning environment, or inhibits students' ability to learn. Faculty in the HSC Schools and the School of Medicine are required to follow their school-specific procedures. Further information about most academic matters can be found in the Undergraduate Bulletin, the Undergraduate Class Schedule, and the Faculty-Employee Handbook.