School of Photovoltaic and Renewable Energy Engineering

UNSW Engineering

SOLA9101

Advanced Photovoltaics

Term 1, 2022

Course Overview

Staff Contact Details

Convenors

Name	Email	Availability	Location	Phone
Ashraf Uddin	a.uddin@unsw.edu.au	Thursday 2pm-4pm (Weekly Consultations)	TETB Room 126	02-9385-9827

Demonstrators

Name	Email	Availability	Location	Phone
Feng Ziyue	ziyue.feng@student.unsw.edu.au	Please contact via MS Teams or email		

School Contact Information

School of Photovoltaic and Renewable Energy Engineering

Email: spreeteaching@unsw.edu.au

Course Details

Units of Credit 6

Summary of the Course

This course covers the basics of the semiconductor materials and advanced photovoltaic devices and processing technology. The major objective is to familiarize the students with the basic principles of operation of all photovoltaic devices such as silicon heterojunction (HIT) cells, multi-junction tandem cells, hot-carrier cells, organic and perovskite solar cells, CIGS, etc. The device processing technology includes: **(i)** crystal structures, silicon crystal growth and Czochralski crystal growth, wafer preparation, defects in wafer, defect treatment, (ii) doping and thermal oxidation of materials, (iii) physical vapor deposition technique, principle of sputtering process, sputtering techniques: RF sputtering, DC magnetrons, bias sputtering, reactive sputtering and ion metal plasma sputtering, (iv) basic aspects of CVD, gas phase mass transfer/surface reaction, rate determining step, sticking coefficient and advantages/disadvantages, types of reactions in CVD: APCVD, LPCVD and PECVD; (v) spin coating, ink-jet printing, micro-contact printing, nanoimprint technology, (vi) Photolithography, photoresist material parameters: resolution, sensitivity and viscosity. Optical photoresist material types, photoresist processing, optics of microlithography, methods of transferring patterns, pattern registration, (vii) wet etching technology, etchants, lift-off technology for patterning electrode, basic physics and chemistry of plasma etching and reactive etching, processing issues related to dry etching.

Course Aims

This course is designed on photovoltaic devices and processing technology. This course is very important to develop the future workforces for solar cells industry. It is essential for students who desire to specialize in photovoltaic devices including micro- and nano-electronics.

Course Learning Outcomes

After successfully completing this course, you should be able to:

Learning Outcome	EA Stage 1 Competencies
1. Explain the physical and electrical properties of semiconductor materials and various photovoltaic device structures.	PE1.1, PE1.3
2. Explain the working principles of advanced photovoltaic devices such as silicon heterojunction (HIT) cells, multi-junction tandem cells, organic and perovskite solar cells, CIGS, etc.	PE1.3, PE1.4
3. Evaluate and analyse performance of different advanced solar cells.	PE1.5, PE2.2
4. Explain silicon crystal growth and the manufacturing processes of devices such as thermal oxidation, dopant diffusion, physical/chemical vapor deposition, spin-coating, photolithography, and etching processes, etc.	PE1.1, PE1.3

Teaching Strategies

The teaching strategy for this course comprises a series of lectures and workshops, problems and classes. The lecture series will present theory related to semiconductor materials and devices and up-to-date information about available equipment, costing, and quality control resources. During workshops, students can also ask demonstrators any questions they may have about the material taught in lectures.

Lectures: There are 10 weeks of Online Lectures (MS Teams) in Term T1, 2022. Each week has two lectures in one- and two-hours slots. The lecture time and places are as: Wednesday 12:00 - 13:00, (MS Teams) and on Thursday 15:00 – 17:00 (MS Teams). All lecture notes will be provided before the lecture, either via UNSW's Moodle site or as photocopied handouts.

Workshops: In the workshop session, students will work in small groups. The workshop problems will be provided before each workshop, either via Moodle or as a photocopied handout. The solutions will be provided during or after each workshop. The workshop schedules for Term T1, 2022 is as: Wednesday 14:00 – 16:00 (Online, MS Teams), Thursday 12:00 – 14:00 (Law building 162, face-to-face).

Assignments: There are two assignments in this course. Assignments will be provided via UNSW's Moodle site. The two take-home assignments will be handed out in weeks 1 and 7. Their due dates will be shown on the papers. The solutions may be presented in the Workshop (but will not be distributed).

Students are also strongly encouraged to use the discussion group on Moodle to assist their learning. Demonstrators will monitor the discussions and help answer posted questions.

Final Exam: Final exam in this course is a standard 2 hour online written examination. University approved calculators are allowed. The examination tests analytical and critical thinking and general understanding of the course material in a controlled fashion. Questions may be drawn from any aspect of the course, unless specifically indicated otherwise by the lecturer. Marks will be assigned according to the correctness of the responses.

Additional Course Information

All course materials and announcements will be posted on Moodle. Please note that you will be deemed to have received this information, so you should take careful note of all announcements.This is a 6 UoC course and the expected workload is 12–14 hours per week throughout the 10-week term. SOLA9101 is a level 5 course. It is offered to 3rd and 4th year UG students and Graduate Diploma and Master's Postgraduate programs students in the School of Photovoltaic and Renewable Energy Engineering School. It is a professional elective course for the Photovoltaic and Solar Energy Program. It is a core/elective course for students following a BE (Materials Science or Electrical Engineering) program and other combined degree programs, and an elective for physics students.

It is assumed that students enrolled in this course are familiar with semiconductor materials and devices such as photovoltaic devices and diodes.

Consultations: For all enquiries about the course, please contact the course convener. A regular weekly consultation time is on Thursday **2 - 4 pm online (MS Teams) or inTETB room 126**. For all other questions or enquiries, you are encouraged to ask the lecturer after class or post your questions on the Discussion Board on Moodle.

https://moodle.telt.unsw.edu.au/login/index.php

Assessment

Assessments

Take-Home Assignment 1&2	20%
Mid-Term Exam	15%
Self-Learning Exam (Term End Test)	15%
Final Exam (2 hours)	50%

- ALL material presented during the sessions will be examinable in the final exam unless otherwise noted.

- All assessable work (except the Final Exam) must be submitted with a completed (and signed) cover sheet. The sheet can be downloaded from the Course Moodle site.

- Late assignments will be penalized 5%, plus 5% per day that the work is late (maximum penalty is 100%). Once the solutions are presented, the maximum penalty will apply.

Assessment task	Weight	Due Date	Course Learning Outcomes Assessed
1. Mid-Term Exam	15%	10/03/2022 12:00 AM	1, 2, 3
2. Assignment - 1	10%	18/03/2022 12:00 AM	1, 2, 3
3. Assignment - 2	10%	22/04/2022 12:00 AM	4
4. Term-End Test	15%	21/04/2022 12:00 AM	4
5. Final Exam	50%	To be confirmed	1, 2, 3, 4

Assessment 1: Mid-Term Exam

Start date: 10/03/2022 12:00 AM
Submission notes: Just after the test, results will be automatically submitted on Moodle
Due date: 10/03/2022 12:00 AM

Mid-term exam will cover all solar cell devices in the course. It will be approximately 40 minutes and will be an online exam.

Assessment criteria

Please see SOLA9101 Moodle site for Assessment Criteria.

Assessment 2: Assignment - 1

Start date: 18/02/2022 12:00 AM
Submission notes: Please submit your assignment in the submission box in Moodle.
Due date: 18/03/2022 12:00 AM
Deadline for absolute fail: Late assignments will be penalized 5%, plus 5% per day that the work is late (maximum penalty is 100%). Once the solutions are presented, the maximum penalty will apply.

Assignment 1 will be provided in week 1 Lecture in Moodle. Students need to solve the assignment 1 problems and submit them in the week 5 Lecture.

Students will have 4 weeks time to solve the problems.

Assessment criteria

Please see SOLA9101 Moodle site for Assessment Criteria.

Assessment 3: Assignment - 2

Start date: 25/03/2022 12:00 AM
Submission notes: Please submit the Assignment 2 solution in the submission box in Moodle.
Due date: 22/04/2022 12:00 AM
Deadline for absolute fail: Late assignments will be penalized 5%, plus 5% per day that the work is late (maximum penalty is 100%). Once the solutions are presented, the maximum penalty will apply.

Assignment 2 will be in Moodle in week 6 Lecture and students need to submit the solution of assignment 2 in week 10 Lecture.

Students will get 4 weeks time to solve the assignment problems.

Assessment criteria

Please see SOLA9101 Moodle site for Assessment Criteria.

Assessment 4: Term-End Test

Start date: 21/04/2022 12:00 AM
Submission notes: Please submit your test results just after the test.
Due date: 21/04/2022 12:00 AM

The Term-End Test will cover all the processing topics. It will be approximately 40 minutes and will be an online exam.

Assessment criteria

Please see SOLA9101 Moodle site for Assessment Criteria.

Assessment 5: Final Exam

Start date: To be confirmed
Assessment length: 2 hours
Submission notes: Just after the exam please submit your answer paper within 30 minutes.
Due date: To be confirmed
Deadline for absolute fail: Late submission will not be accepted.

The Final Exam will cover all the course materials such as lecture notes, workshops and assignments. It will be a 2 hour online exam in Moodle. Just after the exam, students need to submit their answer papers in the submission box in Moodle.

Assessment criteria

Please see SOLA9101 Moodle site for Assessment Criteria.

Attendance Requirements

Students are strongly encouraged to attend all classes and review lecture recordings.

Course Schedule

Contact Hours

Sessions	Day	Time	Location
Lecture	Wednesday	12:00 – 13:00	Online (MS Teams)
Lecture	Thursday	15:00 – 17:00	Online (MS Teams)
Workshop	Wednesday	14:00 – 16:00	Online (MS Teams)
Workshop	Thursday	12:00 – 14:00	Law Bld. 162 (Face-to-Face)

View class timetable

Timetable

Date	Type	Content
Week 1: 14 February - 18 February	Lecture	Lecture Topics: Course outlines and Introduction (L1A), Energy bands and carrier conc. (L1B) Carrier transport Phenomena (L1C). No Workshop week 1
	Assessment	Assignment 1 released
Week 2: 21 February - 25 February	Lecture	Lecture Topics: P-N junction diodes (L2A), Silicon solar cells (L2B) Silicon solar cells (L2C) **& Workshop 1**
Week 3: 28 February - 4 March	Lecture	Lecture Topics: Thin film solar cells (L3A) Silicon heterojunction (HIT) solar cells (L3B)

		Multijunction cells (tandem cells) (L3C) **& Workshop 2**
Week 4: 7 March - 11 March	Lecture	Lecture Topics: Emerging photovoltaic cells (L4A) Emerging photovoltaic cells (L4B) Mid-term exam (L4C) **& Workshop 3**
Week 5: 14 March - 18 March	Lecture	Lecture Topics: Silicon Crystal growth (L5A) Silicon crystal growth (L5B) Diffusion and doping of Si (L5C) **& Workshop 4**
	Assessment	1. Assignment 1 Due
Week 6: 21 March - 25 March	Homework	**Flexibility Week**: No lectures or workshops (Self Study only)
	Assessment	Assignment 2 released
Week 7: 28 March - 1 April	Lecture	Lecture Topics: Oxidation (L7A) Thermal evaporation (L7B) Sputtering (L7C) **& Workshop 5**
Week 8: 4 April - 8 April	Lecture	Lecture Topics: Basic CVD (L8A) Basic CVD (L8B) Spin-coating and ink-jet printing (L8C)

		& Workshop 6
Week 9: 11 April - 15 April	Lecture	Lecture Topics: Lithography (L9A) Lithography (L9B) Etching (L9C) **& Workshop 7**
Week 10: 18 April - 22 April	Lecture	Lecture Topics: Etching (L10A) Lecture Review **& Workshop 8**
	Assessment	1. Assignment 2 Due 2. Term-end test
Study Week: 25 April - 28 April		

Resources

Prescribed Resources

Course Resources

Text and Reference books:

1. S.M. Sze, *Semiconductor Devices (physics and Technology)*, 3rd and 2nd ed. (Wiley, 2012 and 2002).
2. S.M. Sze, "*Physics of Semiconductor Devices*", 3rd Edition (Wiley, 2007); other lecture materials will be drawn from various textbooks and journal papers.
3. M.A. Green, *Solar Cells* (UNSW Bookshop, 1982).
4. Arvind Shah, "Thin-film Silicon solar cells", 2010, CRC press.
5. J. D. Plummer, M. D. Deal and P.B. Griffin, Silicon VLSI Technology, 2000, Prentice Hall.
6. Y. Chang and S.M. Sze, ULSI Technology, 1996, McGraw Hill
7. S. K. Ghandhi, "VLSI Fabrication Principles, 1994, John Wiley.
8. Various Webpages

On-line Resources

- Website: UNSW's Moodle. As a part of the teaching component, Moodle will be used to disseminate teaching materials, host forums and occasionally quizzes. Assessment marks will also be made available via Moodle: https://moodle.telt.unsw.edu.au/login/index.php
- Lecture Notes: Lecture notes will be provided before each lecture via UNSW's Moodle site.
- **Workshops:** Workshop problems will be provided before each workshop via moodle. The solutions will be provided after each workshop in UNSW moodle site.
- Assignments (and other course materials): will be provided via UNSW's Moodle site.
- **PC1D solar cell simulator:** Is installed on the PCs in TETB. For a personal copy, see www.pv.unsw.edu.au/links/products/pc1d.asp.
- Announcements and Discussion Board: Announcements concerning course information will be given in the lectures and/or on Moodle. A Discussion Board will also be established on the Moodle course page for you to post questions or initiate course-related discussions.

Recommended Resources

I am always encouraging my students to discuss with me at any time if my lecture topics are not clear to them. I am also encouraging my students to discuss the lecture topics among themselves to make them clear. I will use workshop problems and assignments from each topic to provide an in-depth understanding on the course. I will run a mid-term test, term-end test and final exam to press the students to study and understand the course content. I will use CATEI reports to improve my course materials and teaching.

Submission of Assessment Tasks

Work submitted late without an approved extension by the course coordinator or delegated authority is subject to a late penalty of 5% mark reduction per day, consistent with other SPREE courses, and capped at 5 days (120 hours), after which a student cannot submit an assessment.

The late penalty is applied per calendar day (including weekends and public holidays) that the assessment is overdue. There is no pro-rata of the late penalty for submissions made part way through a day.

Work submitted after the ‘deadline for absolute fail’ is not accepted and a mark of zero will be awarded for that assessment item.

For some assessment items, a late penalty may not be appropriate. These are clearly indicated in the course outline, and such assessments receive a mark of zero if not completed by the specified date. Examples include:

a. Weekly online tests or laboratory work worth a small proportion of the subject mark, or

b. Online quizzes where answers are released to students on completion, or

c. Professional assessment tasks, where the intention is to create an authentic assessment that has an absolute submission date

or

d. Pass/Fail assessment tasks.

Academic Honesty and Plagiarism

UNSW has an ongoing commitment to fostering a culture of learning informed by academic integrity. All UNSW students have a responsibility to adhere to this principle of academic integrity. Plagiarism undermines academic integrity and is not tolerated at UNSW. *Plagiarism at UNSW is defined as using the words or ideas of others and passing them off as your own.*

Plagiarism is a type of intellectual theft. It can take many forms, from deliberate cheating to accidentally copying from a source without acknowledgement. UNSW has produced a website with a wealth of resources to support students to understand and avoid plagiarism, visit: student.unsw.edu.au/plagiarism. The Learning Centre assists students with understanding academic integrity and how not to plagiarise. They also hold workshops and can help students one-on-one.

You are also reminded that careful time management is an important part of study and one of the identified causes of plagiarism is poor time management. Students should allow sufficient time for research, drafting and the proper referencing of sources in preparing all assessment tasks.

If plagiarism is found in your work when you are in first year, your lecturer will offer you assistance to improve your academic skills. They may ask you to look at some online resources, attend the Learning Centre, or sometimes resubmit your work with the problem fixed. However more serious instances in first year, such as stealing another student's work or paying someone to do your work, may be investigated under the Student Misconduct Procedures.

Repeated plagiarism (even in first year), plagiarism after first year, or serious instances, may also be investigated under the Student Misconduct Procedures. The penalties under the procedures can include a reduction in marks, failing a course or for the most serious matters (like plagiarism in an honours thesis) even suspension from the university. The Student Misconduct Procedures are available here:

www.gs.unsw.edu.au/policy/documents/studentmisconductprocedures.pdf

Academic Information

Course Evaluation and Development

Feedback on the course is gathered periodically using various means, including the UNSW myExperience process, informal discussion in the final class for the course, and the School's Student/Staff meetings. Your feedback is taken seriously, and continual improvements are made to the course based, in part, on such feedback.

All students are expected to read and be familiar with UNSW guidelines and polices. In particular, students should be familiar with the following:

· Attendance

· UNSW Email Address

· Special Consideration

· Exams

· Approved Calculators

· Academic Honesty and Plagiarism

· Equitable Learning Services

CRICOS

CRICOS Provider Code: 00098G

Acknowledgement of Country

We acknowledge the Bedegal people who are the traditional custodians of the lands on which UNSW Kensington campus is located.

Appendix: Engineers Australia (EA) Professional Engineer Competency Standard

Program Intended Learning Outcomes	
Knowledge and skill base	
PE1.1 Comprehensive, theory based understanding of the underpinning natural and physical sciences and the engineering fundamentals applicable to the engineering discipline	✓
PE1.2 Conceptual understanding of the mathematics, numerical analysis, statistics, and computer and information sciences which underpin the engineering discipline	
PE1.3 In-depth understanding of specialist bodies of knowledge within the engineering discipline	✓
PE1.4 Discernment of knowledge development and research directions within the engineering discipline	✓
PE1.5 Knowledge of engineering design practice and contextual factors impacting the engineering discipline	✓
PE1.6 Understanding of the scope, principles, norms, accountabilities and bounds of sustainable engineering practice in the specific discipline	
Engineering application ability	
PE2.1 Application of established engineering methods to complex engineering problem solving	
PE2.2 Fluent application of engineering techniques, tools and resources	✓
PE2.3 Application of systematic engineering synthesis and design processes	
PE2.4 Application of systematic approaches to the conduct and management of engineering projects	
Professional and personal attributes	
PE3.1 Ethical conduct and professional accountability	
PE3.2 Effective oral and written communication in professional and lay domains	
PE3.3 Creative, innovative and pro-active demeanour	
PE3.4 Professional use and management of information	
PE3.5 Orderly management of self, and professional conduct	
PE3.6 Effective team membership and team leadership	