

ELEC4603 Solid State Electronics

Course Staff

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Consultations: You are encouraged to ask questions on the course material before, during and after the lecture class times. Alternatively, queries or concerns about this course can be directed to the Teaching Assistants Mr. Anderson West (laboratory), Mr. Alexis Shaw (laboratory) or Mr. Ross Leon (all other matters) via Moodle, email contact or during prearranged consultation times. ALL email enquiries should be made from your student email address with ELEC4603 in the subject line; otherwise they will not be answered.

Keeping Informed: Announcements may be made during classes, via email (to your student email address) and/or via online learning and teaching platforms – in this course, we will use Moodle <https://moodle.telt.unsw.edu.au/login/index.php>. Please note that you will be deemed to have received this information, so you should take careful note of all announcements.

Course Summary

Contact Hours

The course consists of 2 hours of lectures each week, 1 hour of tutorial and 3 hours of laboratory every two weeks. Tutorials on the **odd (even) week** will commence on the **third (fourth) week** of term. Laboratories on the **even (odd) week** will commence on the **second (third) week** of term. Students should check their myUNSW timetable to see which group they have been allocated to and the corresponding time schedule/location for the Tutorial/Laboratory session.

	Code	Day	Time	Location
Lectures		Wednesday	9am – 11am	Law Th G23
Tutorials	W11A	Wednesday (even wk)	11am – 12noon	CivEng G8
	W11B	Wednesday (odd wk)	11am – 12noon	CivEng G8
	W12A	Wednesday (even wk)	12noon – 3pm	Quad G042
Laboratory	M09A	Monday (even wk)	9am – 12noon	ElecEng G14
	W15A	Wednesday (even wk)	3pm – 6pm	ElecEng G14
	W15B	Wednesday (odd wk)	3pm – 6pm	ElecEng G14
	F11A	Friday (even wk)	11am – 2pm	ElecEng G14
	F11B	Friday (odd wk)	11am – 2pm	ElecEng G14

Assessment scheme

Assessments in this subject will be based on the following scheme:

Laboratory (2 experiments)	20%
Mid-term Examination	10%
Assignment (1)	10%
Final Examination	60%

Indicative Lecture/Tutorial/Laboratory Schedule

Week	Date	Lectures	Tutorials	Experiments
1	28 Feb	Introduction, Course outline <i>Section 1 (Semiconductor Basics)</i> – band structure, doping		
2	7 March	– Intrinsic/extrinsic Si, 1-D semiconductor eqn. <i>Section 2 (Carrier density)</i> – carrier density, Fermi function, law of mass action		<i>Experiment-1: Fibre-Optic Communication (2 lab sessions)</i> <i>Experiment-1: Fibre-Optic Communication</i> (Due to a public holiday on 30 March, the Friday odd week lab of that day is pushed back to Friday week 7)
3	14 March	<i>Section 3 (PN Junctions)</i> basic concepts – depletion layer, band diagrams	<i>Tutorial-1: Derivation of diode IV characteristic</i>	
4	21 March	– PN junctions: derivation of IV characteristic		
5	28 March	– PN diode breakdown, Avalanche, Zener diodes – capacitance, non-idealities	<i>Tutorial-2: Diode design and Thermal effects</i>	
Mid-session break (30 Mar - 8 Apr)				
6	11 April	<i>Section 4 (BJTs)</i> – operation & basic concepts – derivation of IV characteristics	<i>Tutorial-2: Diode design and Thermal effects</i>	<i>Experiment-2: High-Frequency Properties of Transistors (2 lab sessions)</i>
7	18 April	– Ebers-Moll model – non-idealities in BJTs <i>Section 5 (MOSFETs)</i> – Operating principles, threshold voltage	<i>Tutorial-3: Frequency dependent Parameters of BJTs</i>	

8	25 Apr	Anzac Day NO LECTURE OR TUTORIALS		<i>Experiment-2:</i> High-Frequency Properties of Transistors
9	2 May	MID-SESSION TEST <i>Section 5 (MOSFETs) continue</i> – Derivation of IV, equations – non-idealities, fabrication technology in brief <i>Section 6 (Transistors for digital logic)</i> – Introduction	<i>Tutorial-3:</i> Frequency dependent Parameters of BJTs	
10	9 May	– types of MOSFET, logic circuit and properties – BJT logic, TTL concepts	Tutorial-4: TTL circuits	
11	16 May	– TTL and NAND gate analysis, ECL – CMOS logic		
12	23 May	<i>Section 7 (Fabrication of IC)</i> – standard fabrication technique, BJT – fabrication of self-aligned MOSFET – tour to ANFF (optional)	Tutorial-5: CMOS Digital logic circuits	
13	30 May	<i>Section 8 (Optoelectronics)</i> – LEDs, Lasers – issues in fibre optic communication		
EXAM PERIOD: 8 June - 25 June				

Context and Aims

Solid State Electronics expands significantly on the simple models of electronic devices studied in ELEC2133 (Analogue Electronics) and uses concepts of solid-state physics learned in PHYS1231 (Physics 1B). It provides a detailed understanding of the physics, design, operation and limitations of important solid state electronic and optoelectronic devices used by electrical and telecommunications engineers. It is highly relevant for electrical engineers who intend to pursue further studies of integrated circuit design and/or microfabrication.

This subject endeavours to teach students not only just how these electronic devices operate, but also develop some insight into the underlying solid-state physics. The topics to be covered include the following:

- ✓ Band-structure and doping of semiconductors.
- ✓ Drift-Diffusion Equations; Density of states; Fermi function; Law of Mass Action.
- ✓ PN Junctions: Derivation of I-V characteristics.
- ✓ PN Junctions: Capacitance; Breakdown; Non-idealities.
- ✓ Bipolar Junction Transistor (BJT): Operation principles.
- ✓ BJT: Derivation of I-V characteristics.
- ✓ BJT: Ebers-Moll model; Non-idealities.
- ✓ MOSFET: Derivation of I-V characteristics.
- ✓ MOSFET: Structure; Threshold Voltage; Enhancement- & Depletion-mode.
- ✓ Transistors for Digital Logic: TTL, ECL, CMOS.
- ✓ Optoelectronic & Photonic Devices: Direct Vs Indirect Band-gap devices.
- ✓ LEDs; Semiconductor Lasers; Photovoltaic Cells.
- ✓ Principles and key technologies involved in microfabrication of integrated circuits.

- ✓ Microfabrication of: MOSFETs; CMOS; BJTs.

At the end of the course students should:

- understand the underlying operating principles of important microelectronic and photonic devices, such as MOSFETs, BJTs and semiconductor lasers;
- understand the limits of ideal “black-box” models of devices, and predict the effect of these non-idealities on real circuits and systems;
- have an appreciation of the principles of microfabrication relevant to integrated circuit manufacture, and how these affect device performance.

Course Details

Credits

This is a 6 UoC course and the expected workload is 10–12 hours per week throughout the 13 week semester.

Relationship to Other Courses

This is a 4th year undergraduate course in the School of Electrical Engineering and Telecommunications. It is an elective course for computer, telecommunications, and electrical engineering students (including combined degrees).

Pre-requisites and Assumed Knowledge

The prerequisite for Solid State Electronics is ELEC2133 Analogue Electronics. It will be assumed that students have mastered this subject. Students are strongly advised to revise any unfamiliar topics in their own time.

Following Courses

The course is a pre-requisite for the postgraduate level course ELEC9704 VLSI Technology.

Learning outcomes

On successful completion the student should be able to:

- Demonstrate an understanding of the key concepts involved in semiconductor device operation and their characteristics.
- Perform simple analysis of semiconductor devices to derive basic I-V characteristics.
- Predict the effect of device design variations on device performance.
- Assess the relative advantages/disadvantages of different classes of electronic and optoelectronic devices for particular applications.
- Design simple optoelectronic communication systems.
- Demonstrate an understanding of the technologies used in integrated circuit manufacture and the impact of these technologies on device design and performance.

This course is designed to provide the above learning outcomes which arise from targeted graduate capabilities listed in **Appendix A**. The targeted graduate capabilities broadly support the UNSW and Faculty of Engineering graduate attributes (listed in **Appendix B**). This course also addresses the Engineers Australia (National Accreditation Body) Stage I competency standard as outlined in **Appendix C**.

Syllabus

Band-structure and doping of semiconductors. Drift-Diffusion Equations; Density of states; Fermi function; Law of Mass Action. PN Junctions: Derivation of I-V characteristics. PN

Junctions: Capacitance; Breakdown; Non-idealities. Bipolar Junction Transistor (BJT): Operation principles. BJT: Derivation of I-V characteristics. BJT: Ebers-Moll model; Non-idealities. MOSFET: Derivation of I-V characteristics. MOSFET: Structure; Threshold Voltage; Enhancement- & Depletion-mode. Transistors for Digital Logic: TTL, ECL, CMOS. Optoelectronic & Photonic Devices: Direct Vs Indirect Band-gap devices. LEDs; Semiconductor Lasers; Photovoltaic Cells. Principles and key technologies involved in microfabrication of integrated circuits. Microfabrication of: MOSFETs; CMOS; BJTs.

Teaching Strategies

Delivery Mode

The teaching in this course aims at establishing a good fundamental understanding of the areas covered using:

- Formal face-to-face lectures, which provide you with a focus on the core analytical material in the course, together with qualitative, alternative explanations to aid your understanding;
- Tutorials, which allow for exercises in problem solving and allow time for you to resolve problems in understanding of lecture material;
- Laboratory sessions, which support the formal lecture material and also provide you with practical construction, measurement and debugging skills;
- Assignment, in which student can apply what they learnt in class to solve real-world engineering design problems.

Learning in this course

You are expected to attend all lectures, tutorials, laboratories in order to maximise learning. You must prepare well for your laboratory classes and your lab work will be assessed. In addition to the lecture notes, you should read relevant sections of the recommended text. Reading additional texts will further enhance your learning experience. Group learning is also encouraged. UNSW *assumes* that self-directed study of this kind is undertaken in addition to attending face-to-face classes throughout the course.

Tutorial classes

You should attempt all of your problem sheet questions in advance of attending the tutorial classes. The importance of adequate preparation prior to each tutorial cannot be overemphasized, as the effectiveness and usefulness of the tutorial depends to a large extent on this preparation. Group learning is encouraged. Answers for these questions will be discussed during the tutorial class and the tutor will cover the more complex questions in the tutorial class. The solution for tutorial questions may not be made available on the web, so it is worthwhile for you to attend your tutorial and **actively involve in discussion** to gain maximum benefit from the tutorial session.

Laboratory program

You are required to attend laboratory through out the semester. Laboratory attendance WILL be kept, and you MUST attend at least 80% of labs.

Electronics is very much an experiment-oriented subject. Successful practical implementation of designs and effective reporting of results are of crucial importance in developing your skills as a competent electronics engineer.

The experimental component of this course is complementary to the lectures. In it, students will have the opportunity to gain experience with the use of optoelectronic devices, as well as

to characterise the dc parameters of a BJT and a MOSFET, and explore their high-frequency properties.

A pass grade in all laboratory experiments is required to pass this course overall. All of the experiments are compulsory and are worth, in total, 20%.

The preliminary preparation for each laboratory experiment consists in reading through the laboratory notes and familiarising yourself with the concepts involved. Ensure that you understand what each experiment is about before the relevant laboratory session.

Keeping systematic notes is an important aspect of experimental technique. Your laboratory notebooks should be the primary record of your design and calculations and results of your experiments. The preliminary preparation should be done in the laboratory notebook. Results, measurement and observations should be recorded directly into the notebook as they are gathered (and not on loose scraps of paper). Except when drawing circuits and waveforms, pen must be used rather than pencil. There is no need to do a 'draft' and then a 'good copy' — this merely wastes time.

The notes for laboratory experiments may be downloaded from the course web-site. The experiments are:

Exp 1. Fibre-Optic Communication	(2 lab sessions)
Exp 2. High-Frequency Properties of Transistors	(2 lab sessions)

Laboratory sessions are scheduled every alternate week, i.e., you attend a laboratory period every odd week or every even week, depending on your lab allocation. **Showing up in the wrong lab session for the first experiment may result in a penalty on your lab mark. Please consult your myUNSW timetable before hand to find out which lab group you have been allocated to.**

Please take careful note of the **laboratory experiment completion deadlines.**

Laboratory Arrangement

Each student will be allocated a bench number. It is essential that students conduct their experiment at the allocated bench position; otherwise they will be marked absent. Work in a group of 2, however each student must have their own lab book record and will be assessed individually.

You are expected to work on the experiment **on your own** and copying is an infringement of university examination regulations. Discussion on experimental work is encouraged, but over zealous assistance should be avoided.

Laboratory Exemption

There is no laboratory exemption for this course. Regardless of whether equivalent labs have been completed in previous courses, all students enrolled in this course for Semester 1, 2016 must take the labs. If, for medical reasons, (note that a valid medical certificate must be provided) you are unable to attend a lab, you will need to apply for a catch-up lab during another lab time, as agreed by the teaching assistant Mr. Ross Leon or Mr. Anderson West.

Assessment

The assessment scheme in this course reflects the intention to assess your learning progress through the semester. Ongoing assessment occurs through the lab checkpoints, assignment and final exam. There will be NO mid-semester exam, laboratory exam in this course. All parts

of the assessment will be marked according to the amount of work done, the correctness of the work, and the displayed knowledge and understanding of the topic.

You must pass (attain more than 50% of the total marks) both the laboratory component and the exam component to pass the course.

Laboratory Assessment (20%)

Demonstrators will strictly follow the guideline below during the assessment:

- 1) All preliminary preparation, results of experimental measurements and discussion of results **must be neatly recorded** in a laboratory book. **Work presented in loose sheets will NOT be marked.**
- 2) **Assessment of your work will be conducted orally.** It is the student's responsibility to organise the documentation of his laboratory work in a fashion that shows his/her understanding and achievements. During the oral examination, **students are expected to demonstrate the operation of their circuit.** Do not dismantle the circuit until you have received a written clearance in your laboratory note book that the assessment is complete.
- 3) Each experiment will be marked out of **20 points**.
- 4) Marking will only be done during the laboratory period by the demonstrators present. It is the responsibility of the students to make sure that his/her mark is recorded by the demonstrator. Experiments will only be marked during a student's assigned lab time. Do not attend another lab group to get marked unless permission has been given by a demonstrator.

Deadline for Marking of Laboratory Work

The laboratory experiments for this subject have to be completed and marked by the following dates.

Exp 1: Even-Week Groups: **Week4**/Odd-Week Group: **Week5**)

Exp 2: Even-Week Groups: **Week8**/Odd-Week Group: **Week9**)

Each laboratory experiment is worth 20 points. If you are **late by less than 1 week, 5 points** will be deducted. A further **5 points** will be deducted for each additional week late. Even if you have no points left, **you must still satisfactorily complete the laboratory work to pass the course.** Note that the deadlines merely represent the last day an experiment can be marked without penalty.

Assignment (10%)

The assignment allows self-directed study leading to the solution of partly structured problems. Marks will be assigned according to how completely and correctly the problems have been addressed and the understanding of the course material demonstrated by the report.

There will be one compulsory written **assignment**. It is expected that the students complete assignments on their own. **Students found guilty of academic misconduct, including excessive collaboration, copying another's assignment, or allowing one's assignment to be copied by another student, will not receive any marks for that assignment.** In addition, a more severe penalty may be imposed.

Late submissions will attract a penalty of 10% per day (including weekends). All assignment report, both hand written or typed, should be carefully converted into pdf file and forward it to teaching assistant Mr. Ross Leon (ross.leon@unsw.edu.au) through email.

Before submitting your report, make sure of the following:

- Report is complete, any missing page due to scan will **NOT** be assessed. Late penalty will be applied if the missing page is submitted after the deadline.
- Report is reasonably easy to read, typing report is not compulsory but make sure your answer is as neat as possible.
- Make sure the school individual assignment cover sheet is signed and attached at the first page. The report without cover sheet will **NOT** be assessed. You may find the cover sheet through the link:

<http://scoff.ee.unsw.edu.au/forms/Individualassignmentcover.pdf>

Mid-term Exam (10%)

There will be a closed-book 1-hour written exam near the mid-session break. More information about the mid-term will be available in the first few weeks of the course.

Final Exam (60%)

The exam in this course is a standard closed-book 2 hour 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 (including laboratory), unless specifically indicated otherwise by the lecturer. Marks will be assigned according to the correctness of the responses. **Please note that you must pass the final exam in order to pass the course.**

Relationship of Assessment Methods to Learning Outcomes

Assessment	Learning Outcomes					
	1	2	3	4	5	6
Laboratory practical assessments	✓	-	✓	✓	✓	-
Assignment	✓	✓	-	✓	-	-
Final exam	✓	✓	✓	✓	-	✓

Course Resources

Textbooks

The textbook set for this course is:

**Muller & Kamins, *Device Electronics for Integrated Circuits*, 3rd ed., Wiley, 2003
- P621.3815/308 (UNSW Library)**

An alternative textbook, which covers much of the same material, but with greater emphasis on semiconductor fabrication, is:

**S. M. Sze, *Semiconductor Devices: Physics and Technology*, 2nd ed., Wiley, 2002
- P621.38152/120 (UNSW Library)**

In addition to the textbooks, which combine the semiconductor devices and electronics, other reference books include semiconductor device textbooks and electronic circuit textbooks. For semiconductor devices, a series of books which covers operation of devices in a clear, readable manner with many good analogies and explanations is *The Modular Series on Solid State Devices* edited by R.F. Pierret and G.W. Nuedeck. Each volume is short, covering a specific topic only. The volumes of interest are I, II, III and IV. Although the material is covered at a basic level, the treatment is very complete and, consequently, for this course, not all sections are relevant.

The material covered by textbooks dealing exclusively with electronics circuits has remained relatively unchanged over many years and consequently there are many well-polished textbooks. Three of the more popular ones are listed below. Of the three, Millman & Grabel has a more theoretical and complete approach, particularly for feedback and frequency response. Sedra & Smith has the best coverage of device fabrication. Burns & Bond approaches electronic circuits from a semiconductor physics perspective and was formerly the textbook for this course. All three textbooks have some coverage of digital circuits.

Sedra & Smith, *Microelectronic Circuits*, 4th ed., Oxford University Press, 1998.
Millman & Grabel, *Microelectronics*, McGrawHill, 2nd ed., NY.
Burns & Bond, *Principles of Electronic Circuits*, PWS, 2nd ed., 1997.

Finally, for those interested in designing and building realistic functioning circuits, a variety of books exists which give examples of many types of circuits. Several such books exist, but a well-respected and popular anthology of circuits with many useful practical tips is *The Art of Electronics*.

Horowitz & Hill, *The Art of Electronics*, 2nd ed., Cambridge University Press, 1989.

On-line resources

Moodle

As a part of the teaching component, Moodle will be used to disseminate teaching materials and host forums. Assessment marks will also be made available via Moodle: <https://moodle.telt.unsw.edu.au/login/index.php>.

Mailing list

Announcements concerning course information will be given in the lectures and/or on Moodle and/or via email (which will be sent to your student email address).

Other Matters

Academic Honesty and Plagiarism

Plagiarism is the unacknowledged use of other people's work, including the copying of assignment works and laboratory results from other students. Plagiarism is considered a form of academic misconduct, and the University has very strict rules that include some severe penalties. For UNSW policies, penalties and information to help you avoid plagiarism, see <http://www.lc.unsw.edu.au/plagiarism>. To find out if you understand plagiarism correctly, try this short quiz: <https://student.unsw.edu.au/plagiarism-quiz>.

Student Responsibilities and Conduct

Students are expected to be familiar with and adhere to all UNSW policies (see <https://my.unsw.edu.au/student/atoz/ABC.html>), and particular attention is drawn to the following:

Workload

It is expected that you will spend at least **ten to twelve hours per week** studying a 6 UoC course, from Week 1 until the final assessment, including both face-to-face classes and *independent, self-directed study*. In periods where you need to complete assignments or prepare for examinations, the workload may be greater. Over-commitment has been a common source of failure for many students. You should take the required workload into account when planning how to balance study with employment and other activities.

Attendance

Regular and punctual attendance at all classes is expected. UNSW regulations state that if students attend less than 80% of scheduled classes they may be refused final assessment.

General Conduct and Behaviour

Consideration and respect for the needs of your fellow students and teaching staff is an expectation. Conduct which unduly disrupts or interferes with a class is not acceptable and students may be asked to leave the class.

Work Health and Safety

UNSW policy requires each person to work safely and responsibly, in order to avoid personal injury and to protect the safety of others.

Special Consideration and Supplementary Examinations

You must submit all assignments and attend all examinations scheduled for your course. You should seek assistance early if you suffer illness or misadventure which affects your course progress. All applications for special consideration must be **lodged online through myUNSW within 3 working days of the assessment**, not to course or school staff. For more detail, consult <https://my.unsw.edu.au/student/atoz/SpecialConsideration.html>.

Continual Course Improvement

This course is under constant revision in order to improve the learning outcomes for all students. Please forward any feedback (positive or negative) on the course to the teaching assistant, Mr. Anderson West, Mr. Alexis Shaw, Mr. Ross Leon, or via the Course and Teaching Evaluation and Improvement Process. You can also provide feedback to ELSOC who will raise your concerns at student focus group meetings. As a result of previous feedback obtained for this course and in our efforts to provide a rich and meaningful learning experience, we have continued to evaluate and modify our delivery and assessment methods.

Administrative Matters

On issues and procedures regarding such matters as special needs, equity and diversity, occupational health and safety, enrolment, rights, and general expectations of students, please refer to the School and UNSW policies:

<http://www.engineering.unsw.edu.au/electrical-engineering/policies-and-procedures>
<https://my.unsw.edu.au/student/atoz/ABC.html>

Appendix A: Targeted Graduate Capabilities

Electrical Engineering and Telecommunications programs are designed to address the following targeted capabilities, which were developed by the school in conjunction with the requirements of professional and industry bodies:

- The ability to apply knowledge of basic science and fundamental technologies;
- The skills to communicate effectively, not only with engineers but also with the wider community;
- The capability to undertake challenging analysis and design problems and find optimal solutions;
- Expertise in decomposing a problem into its constituent parts, and in defining the scope of each part;
- A working knowledge of how to locate required information and use information resources to their maximum advantage;
- Proficiency in developing and implementing project plans, investigating alternative solutions, and critically evaluating differing strategies;
- An understanding of the social, cultural and global responsibilities of the professional engineer;
- The ability to work effectively as an individual or in a team;
- An understanding of professional and ethical responsibilities;
- The ability to engage in lifelong independent and reflective learning.

Appendix B: UNSW Graduate Capabilities

The course delivery methods and course content directly or indirectly addresses a number of core UNSW graduate capabilities, as follows:

- Developing scholars who have a deep understanding of their discipline, through lectures and solution of analytical problems in tutorials and assessed by assignments and written examinations.
- Developing rigorous analysis, critique, and reflection, and ability to apply knowledge and skills to solving problems. These will be achieved by the laboratory experiments and interactive checkpoint assessments during the labs.
- Developing capable independent and collaborative enquiry, through a series of tutorials spanning the duration of the course.
- Developing digital and information literacy and lifelong learning skills through assignment work.

Appendix C: Engineers Australia (EA) Professional Engineer Competency Standard

	Program Intended Learning Outcomes	
PE1: Knowledge and Skill Base	PE1.1 Comprehensive, theory-based understanding of underpinning fundamentals	✓
	PE1.2 Conceptual understanding of underpinning maths, analysis, statistics, computing	✓
	PE1.3 In-depth understanding of specialist bodies of knowledge	✓
	PE1.4 Discernment of knowledge development and research directions	
	PE1.5 Knowledge of engineering design practice	✓
	PE1.6 Understanding of scope, principles, norms, accountabilities of sustainable engineering practice	
PE2: Engineering Application Ability	PE2.1 Application of established engineering methods to complex 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	
PE3: Professional and Personal Attributes	PE3.1 Ethical conduct and professional accountability	
	PE3.2 Effective oral and written communication (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	✓