MSc Solar Energy Engineering (SEE)

Module Handbook

(as of January 2020)

University of Freiburg

MSc Solar Energy Engineering (SEE)
Module Handbook

4th Edition – January 2020

University of Freiburg
Department of Microsystems Engineering - IMTEK
Georges-Koehler-Allee 10
79110 Freiburg, Germany

In scientific cooperation with
Fraunhofer Institute for Solar Energy Systems ISE
Heidenhofstr. 2
79110 Freiburg, Germany

Contents

1. General Regulations

1.1. Profile and Concept of the Master Program

The following academic and examination regulations hold for the postgraduate program Master of Science Solar Energy Engineering at the University Freiburg. After successful completion of this Master program the academic degree Master of Science (abbreviated M.Sc.) is awarded.

The internationally oriented Master program in English language offers students a broad interdisciplinary engineering and science education in the field of solar power generation. The aim of this Master program is to train highly qualified engineers with professional competence starting from the development and production of photovoltaic semiconductor components or solar thermal collectors up to the construction of complex power grids integrating photovoltaic or solar thermal systems. This will particularly enhance the students' capability to optimize systems, components and plants taking into account the aspects of innovation, efficiency, cost and durability.

It is designed as a part-time postgraduate program and integrates the various possibilities offered by distance learning and by information and communication technology (multimedia learning).

1.2. Regular Study Period and European Credit Transfer and Accumulation System (ECTS)

The postgraduate program M.Sc. Solar Energy Engineering starts in the Winter Semester (October). The courses offered within this program are repeated annually and are divided into Preparatory, Mandatory and Elective Modules as well as into Research Projects and the Master thesis.

This program takes the students from a Bachelor's degree (B.Sc.) to a Master's degree in only three years part-time studies (Broad Track). Students who already hold a Master's degree (M.Sc.) may shift their career into the solar energy sector in only two years part-time studies (Fast Track). Depending on the student's latest university degree, the scope of the Master program varies from 60 ECTS (fast track) to 120 ECTS (broad track). According to the European Credit Transfer and Accumulation System (ECTS) one ECTS credit point corresponds to an average study-workload of 25 hours. ECTS credit points are awarded for successful academic achievements, module examinations and the master thesis.

1.2.1. Broad Track of the MSc Solar Energy Engineering

The Broad Track is meant for students new to the field and with only little prior knowledge in the different disciplines relevant for the Master program. The Preparatory Modules give a sound introduction to these disciplines and a solid knowledge basis to comprehend the more advanced and specialized courses in the Mandatory Modules.

Students with a B.Sc. or B.Eng. degree with 180 ECTS (equivalent to a ~3 year full-time study degree) with at least 90 ECTS in Math, Physics, and Electrical Engineering are eligible for the broad track of the M.Sc. Solar Energy Engineering program (Figure 1).

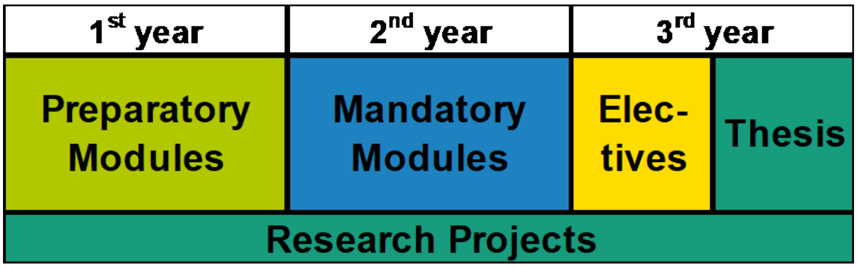

Figure 1: Broad Track for students with a 3-4 year B.Sc./B.Eng. or M.Sc. degree without final thesis.

Students holding a Bachelor with additional 30 ECTS (in total 210 ECTS) and who wrote a final thesis accounting for at least 15 ECTS may be able to skip the research project modules (Figure 2).

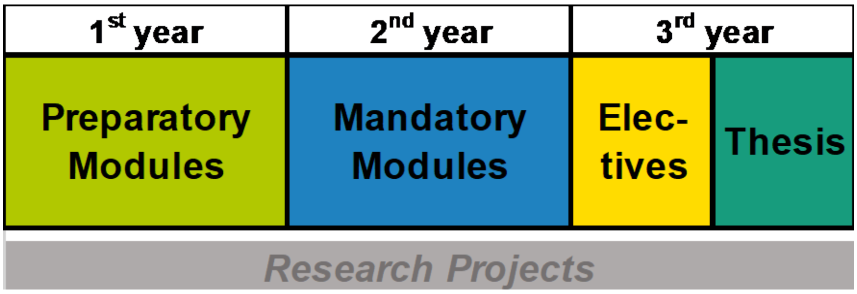

Figure 2: Broad Track for students with a 4-5 year B.Sc./B.Eng. or a M.Sc. degree with a final thesis.

1.2.2. Fast Track of the MSc Solar Energy Engineering

The Fast Track is meant for students who already have prior knowledge in the different disciplines relevant for the Master program and who therefore don't need to take the Preparatory Modules.

Students with a B.Sc./B.Eng. or a M.Sc. degree who cumulated at least 210 ECTS (equivalent to a ~4 year's full-time study degree) in Physics, Electrical Engineering or any similar field and which have a solid background in the physics of semiconductors are eligible for the fast track (Figure 3).

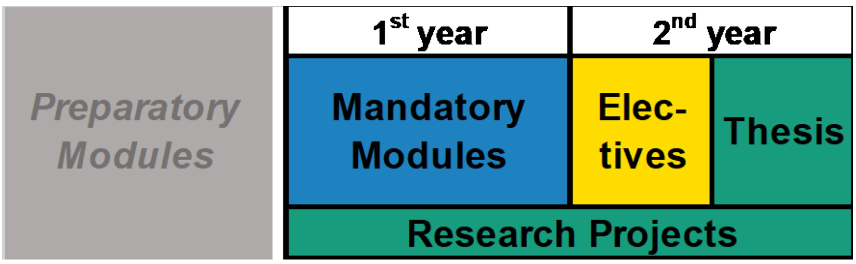

Figure 3: Fast Track for students with a 4-5 years B.Sc./B.Eng. or a M.Sc. degree in Electrical Engineering or Physics, with background in the physics of semiconductors.

Students with a B.Sc./B.Eng. or a M.Sc. degree with at least 240 ECTS (equivalent to a 5 year's full time study degree) in Physcis, Electrical Engineering or any similar field and who wrote a final thesis of at least 30 ECTS during their previous study may be able to skip the research project modules (Figure 4).

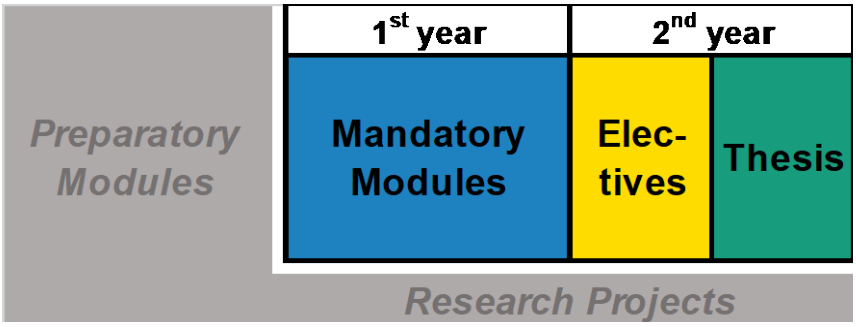

Figure 4: Fast Track for students with a 5 years B.Sc./B.Eng. or a M.Sc. degree in Electrical Engineering or Physics, a final thesis and with background in the physics of semiconductors.

1.3. Study Format

During the study period, students work through the audio and video lectures, the readings and the exercise sheets that are provided on the learning platform. Self-study of the provided reading material supports the understanding. Online meetings with the lecturers and tutors are arranged for the students during this self-study phase to ask questions, discuss problems and exercise sheets. To independently contact lectures and tutors in each course, a forum is provided. In order to strengthen the learning effect, each course has an exam, presentation or scientific report at the end of the semester.

1.3.1. E-Lectures

Short e-lectures are provided for online learning. The e-lectures function as introduction into a topic and as overview of a specific field within a module. The e-lectures have a length of around 20 minutes and a narrow focus on a specific topic.

1.3.2. Reading Material

Reading material is available for each topic to support the e-lectures or provide an alternative entry into the course's content. The most relevant books and journal publications are provided. References through the e-lectures point towards the most relevant parts.

1.3.3. Regular Online Meetings

Online meetings are an important way to discuss with your lecturer and/or tutor about the reading materials, e-lectures as well as exercises and tests. The Online Meetings are scheduled in such a way that all students from different time zones have a chance to attend. They can also be scheduled individually with the lectures or tutors. If it happens that students could not attend an online meeting, the recordings of the meetings made available to all students can be watched afterwards.

1.3.4. Exercise Sheets

Most of the courses offered in the SEE use exercise sheets. The exercise sheets will be provided online during the semester. The students should hand in the solutions to the exercise sheets typically one week before the respective online meeting in order to discuss problems faced during solving. A standard solution will be provided during or after the online meeting. The exercise sheets may contribute to the student's final grade, and the exam problems in many courses follow the same logic as the problems covered in the exercise sheets.

1.4. Exam Regulations

In order to pass the written exams of the different courses, students need to achieve at least the grade 4.0 (sufficient) in the German grading system (see Table 1). The written exams take place in Freiburg during the Campus Phase or simultaneously worldwide at a Goethe-Institute or a recognized partner university. The exam, presentation or lab journal of each part (course/ seminar/ hands-on) must be passed to successfully complete a module. The final grade is composed from the single grades of each part, weighted after the arithmetic mean considering the ECTS credit points for each course. For being awarded credit points it is required that students:

- Take active part in each course/ seminar/ hands-on of the module and in its online meetings.
- Study on their own (self-study) and independently prepare and rework the lectures and reading materials.
- Take the exams, perform presentations in the seminars and participate in the hands-on course including writing a lab journal during the Campus Phase.

1.4.1. Grading system

Grades are awarded according to the German grading scale (1-5) specified in Table 1.

Table 1: Grades according to the German and ECTS grading system and their definition.

ECTS system	German system	
A	1	excellent/ outstanding performance
B	2	good performance that meets the standard completely and is above-average
C	3	satisfactory/ average performance
D	4	sufficient/ standard has been met but with a number of notable errors
F	5	insufficient/ failed

For a finer evaluation of assessed work, decimal grades may be given by raising or lowering the grade by 0.3. The grades 0.7, 4.3, 4.7 and 5.3 are barred. An overview about the awarded grades can be seen in Table 2.

Table 2: Numerical grades and their awarded names.

Decimal Grade	Grade awarded
1.0 to 1.5	very good
1.6 to 2.5	good
2.6 to 3.5	satisfactory
3.6 to 4.0	sufficient
more than 4.0	insufficient

1.4.2. Failing and Repeating of Exams

Any assessment in a given subject which is graded as “insufficient” (5.0) or which is considered a fail can be repeated once. During the whole study program, a maximum of two subject-specific assessments that were considered a fail can be repeated more than one time, meaning repeated twice. This restriction does not comprise the Master’s Module.

If desired by the students, up to two assessments which were successfully passed can each be repeated once for the purpose of obtaining a better grade. In each case, the assessment with the better grade will be counted in the end. In order for this to be counted, students must repeat the assessment prior to submitting the Master's thesis.

2. Responsible Persons

2.1. Scientific Director

Professor Dr. Leonhard M. Reindl
University of Freiburg
Department of Microsystems Engineering – IMTEK
Chair for Electrical Instrumentation
Georges-Koehler-Allee 106
79110 Freiburg, Germany

2.2. Program Coordination

Philipp Bucher
Program Coordinator
University of Freiburg
Department of Microsystems Engineering – IMTEK
Laboratory for Electrical Instrumentation
Georges-Koehler-Allee 106
79110 Freiburg, Germany

2.3. Admission and Examination Board

The admission and examination board of SEE consists of three professors as main members and one professor in the function of a deputy. The board is elected for a period of three years. From 2019 to 2021 the members are:

- Prof. Dr. Leonhard M. Reindl, IMTEK
- Prof. Dr. Anke Weidlich, INATECH
- Prof. Dr. Stefan Glunz, INATECH

As deputy acts:

- Prof. Dr. Moritz Diehl, IMTEK

2.4. Teaching Staff

The teaching staff is composed of professors and lecturers of the University of Freiburg, the Fraunhofer Institute for Solar Energy Systems, and private lecturers with expertise in the field of photovoltaics and solar energy engineering.

(A list of all lectures and tutors is attached in the appendix, Table 5)

3. Overview of all Modules

This section gives an overview about all modules and courses which are currently part of SEE.

Table 3: Module Overview

Modules	*Lecturer*	*ECTS*
PREPARATORY MODULES		**30**
Module A: The Global Energy Needs in a Nutshell	W. Hoffmann	5
Module B: Fundamentals of Math and Physics		**10**
B.1 – Mathematical Methods	M. Datcheva	4
B.2 – Physical Methods	M. Glatthaar	6
Module C: Fundamentals of Semiconductors		**12**
C.1 – Semiconductor Processing Technology	M. Zacharias	4
C.2 – Solid State and Semiconductor Physics	Ch. Nebel	8
Module D: Electrical Engineering and Power Electronics	O. Stalter	3
MANDATORY MODULES		**30**
Module 1: Solar Cells & Photovoltaic Systems		**10**
1.1 – Solar Cells	U. Würfel	5
1.2 – Photovoltaic Systems	R. Rüther	5
Module 2: Solar Thermal Systems		**10**
2.1 – Fundamentals of Solar Thermal Collectors	W. Platzer	5
2.2 – Solar Thermal Systems Engineering	W. Platzer	5
Module 3: Crystalline Silicon Photovoltaics		**10**
3.1 – Feedstock and Crystallization	M. Schubert	2
3.2 – Silicon Solar Cells – Structure and Analysis	S. Glunz	2
3.3 – Solar Cell Production Technology	R. Preu	2
3.4 – Silicon Module Technology and Reliability	H. Wirth	2
3.5 – Hands-on Solar Cell Processing	J. Rentsch	2
RESEARCH PROJECTS		**30**
Module R: Research Projects		**30**
R.1 – Advanced Research Skills	Th. Hanemann	5
R.1b – R.3b – Research Projects 1b, 2a, 2b, 3a, 3b		5x5
MASTER MODULE		**15**
Module M – Master Module		15
ELECTIVE MODULES	free choice of	**15**
Topic: Characterization & Modelling		*10*
Module CM1: Material and Solar Cell Characterization		**5**
CM1.1 – Material and Solar Cell Characterization	M. Schubert	3
CM1.2 – Hands-on Measurement Instrumentation	J. Haunschild	2
Module CM2: Device Modelling		**5**
CM2.1 – Numerical Simulation of Solar Cells	J. Schumacher	5
Topic: Photovoltaic Systems & Grids		*10*
Module PG1: Electronics for Photovoltaic Systems		**6**
PG1.1 – Selected Semiconductor Devices	O. Höhn	2
PG1.2 – Grid Integration and Control of PV Systems	S. Reichert	4
Module PG2: Renewable Energy Systems & Smart Grids		**4**
PG2.1 – Technologies for Renewable Energy Conversion	Th. Schlegl	2
PG2.2 – Smart Grids & Energy Autonomous Communities	Ch. Wittwer	2
Topic: Solar Cell Technologies		*10*
Module ST1: Thin-Film and Concentrator Photovoltaics		**7**
ST1.1 – Inorganic Thin-Film Solar Cells	M. Powalla	4
ST1.2 – III-V Solar Cells and Concentrator Systems	G. Siefer	3
Module ST2: Advanced Processing & New Cell Concepts		**3**
ST2.1 – New Concepts for PV Energy Conversion	U. Würfel	2
ST2.2 – Advanced Solar Cell Processing	M. Heinrich	1

4. Detail of the Modules

4.1. Preparatory Modules

4.1.1. Module A – The Global Energy Needs in a Nutshell

Module Code	*Module Name*
A	**The Global Energy Needs in a Nutshell**
Courses	
No. A.1	The Global Energy Needs in a Nutshell

Prerequisites	*Type of Module*	*Rotation*
None	Preparatory	Winter Semester

Type of Courses	*Instruction Language*
Online Lectures	English
Type of examination	*Workload*
Written homework	125 h (5 ECTS)
Module coordinator	*Additional teachers involved*
Dr. Winfried Hoffmann	None

Syllabus

This module provides comprehensive knowledge regarding the fundamentals of the global energy needs in the future. All kind of renewable energy systems will be introduced and discussed with special focus on photovoltaic systems.

Learning outcomes

After successful completion of this module students should be able to:

- understand all kinds of renewable energy systems that will be used in future as a whole picture.
- discuss the influence of renewable energy systems.
- understand the basic functionality of photovoltaic systems and solar cells.

4.1.2. Module B – Fundamentals of Math and Physics

Module Code	*Module Name*
B	**Fundamentals of Math and Physics**
Courses	
No. B.1	Mathematical Methods
No. B.2	Physical Methods

Prerequisites	*Type of Module*	*Rotation*
None	Preparatory	Winter Semester

Type of Courses	*Instruction Language*
Online Lectures	English
Type of examination	*Workload*
Written exam	250 h (10 ECTS)
Module coordinator	*Additional teachers involved*
Prof. Maria Datcheva	Dr. Markus Glatthaar

Syllabus

This module covers the fundamentals of mathematical and physical methods in order to prepare the students for the contents of the mandatory modules.

1) **Mathematical Methods**: This course provides an introduction to the mathematical methods that are a prerequisite to understand energy conversion principles and to perform research on solar energy.
2) **Physical Methods**: The aim of this course is to discuss on a rather basic level some of the fundamental physical principles relevant to the understanding of the working and technology of solar energy. This involves the areas of thermodynamics, electromagnetism, optics and quantum mechanics.

Learning outcomes

After successful completion of this module students should be able to:

- calculate the light reflection and optical charge generation in a semiconductor.
- calculate the time-dependent charge excitation of a wafer for the model-based characterization.
- simulate the doping-profile in a semiconductor wafer that results from surface diffusion of a dopant during a fabrication step.
- explain basic principles of physics relevant for the understanding of solar cell physics and technology.

4.1.3. Module C – Fundamentals of Semiconductor

Module Code	*Module Name*
C	**Fundamentals of Semiconductor**
Courses	
No. C.1	Semiconductor Devices and Processing Technology
No. C.2	Solid State and Semiconductor Physics

Prerequisites	*Type of Module*	*Rotation*
Module B	Preparatory	Summer Semester

Type of Courses	*Instruction Language*
Online Lectures	English
Type of examination	*Workload*
Written or oral exam	300 h (12 ECTS)
Module coordinator	*Additional teachers involved*
Prof. Margit Zacharias	Prof. Christof Nebel

Syllabus

This module provides comprehensive fundamental knowledge regarding the physical properties of semiconductor materials. Solar cells are solid electronic devices made from silicon, germanium, carbon, GaN and other semiconductor materials. The number of optically generated carries per photon and the electronic performance ("efficiency") depend on the optical and physical properties of semiconductors, which will be introduced and explained in this module.

1) **Semiconductor Devices and Processing Technology:** This course provides an introduction to the fundamental processes that are required to produce semiconductor devices.
2) **Solid State and Semiconductor Physics:** This lecture can be considered as foundation to all other lectures of this master course. It will help students to understand the limits of efficiencies, the device performance at different temperatures and environments taking into account homo- and hetero-junction solar cells.

Learning outcomes

After successful completion of this module students should be able to:

- understand and describe semiconductor devices on the basis of fundamental concepts of solid state physics, thermodynamics, optics and quantum mechanics.
- understand the fundamental processes that are required to produce semiconductor devices.

4.1.4. Module D – Electrical Engineering and Power Electronics

Module Code	*Module Name*
D	**Electrical Engineering and Power Electronics**
Courses	
No. D.1	Electrical Engineering and Power Electronics

Prerequisites	*Type of Module*	*Rotation*
Module B	Preparatory	Summer Semester

Type of Courses	*Instruction Language*
Online Lectures	English
Type of examination	*Workload*
Written exam	75 h (3 ECTS)
Module coordinator	*Additional teachers involved*
Dr. Olivier Stalter	None

Syllabus

This module gives a basic introduction into electrical engineering in order to prepare the students for the contents of the mandatory modules. The mathematical fundamentals and models of electrical engineering which are required to understand how PV systems (DC), electricity grids (AC) and power electronics converters operate. Topologies such as the buck-converter, boost-converter, single phase and three-phase inverter will be explained in detail.

Learning outcomes

After successful completion of this module students should be able to:

- understand and describe mathematically the electrical DC and AC processes happening in electrical power systems and converters.
- model the operating principle of basic power converter topologies and explain the function of their active and passive components.

4.2. Mandatory Modules

4.2.1. Module 1 – Solar Cells and Photovoltaic Systems

Module Code	*Module Name*
1	**Solar Cells and Photovoltaic Systems**
Courses	
No. 1.1	Solar Cells
No. 1.2	Photovoltaic Systems

Prerequisites	*Type of Module*	*Rotation*
Module A, B, C and D	Mandatory	Winter Semester

Type of Courses	*Instruction Language*
Online Lectures	English
Type of examination	*Workload*
Written exam	250 h (10 ECTS)
Module coordinator	*Additional teachers involved*
Dr. Uli Würfel	Dr. Ricardo Rüther

Syllabus

This module provides comprehensive knowledge regarding the fundamental physical processes of solar cells and photovoltaic systems.

1) **Solar Cells:** This course builds the basis for all solar cell related modules in the following studies. Understanding the basics of solar cells is an essential prerequisite for all scientific and technological activities in photovoltaics.
2) **Photovoltaic Systems**: This course gives a wide overview on multiple considerations related to the design, installation and optimization of photovoltaic (PV) systems on the field. The knowledge provided in this lecture will be of valuable assistance to the students in order to understand the interaction of several system components as well as their influence on PV energy production.

Learning outcomes

After successful completion of this module students should be able to:

- understand the fundamental physical processes of photovoltaic energy conversion.
- describe the fundamental operating principles of photovoltaic devices.
- design and optimize photovoltaic systems based on their understanding of the environment and its influence on photovoltaic energy conversion.
- describe and design photovoltaic systems for optimized energy production, transport and storage.

4.2.2. Module 2 – Solar Thermal Systems

Module Code	*Module Name*
2	**Solar Thermal Systems**
Courses	
No. 2.1	Fundamentals of Solar Thermal Collectors
No. 2.2	Solar Thermal Systems Engineering

Prerequisites	*Type of Module*	*Rotation*
Module A and B	Mandatory	Winter Semester

Type of Courses	*Instruction Language*
Online Lectures	English
Type of examination	*Workload*
Written exam	250 h (10 ECTS)
Module coordinator	*Additional teachers involved*
Prof. Werner Platzer	None

Syllabus

This module gives a wide overview on solar thermal systems and their main components. Starting with basic issues of physical processes and design options for non-concentrating and concentrating solar thermal collectors, systems engineering based on these technologies are presented. The complex systems for different applications ranging from solar water heating to process heat for industry to solar thermal power production are described.

1) **Fundamentals of Solar Thermal Collectors:** The course gives an overview over optical and thermal characteristics of solar thermal collector technologies, from flat-plate collectors to solar tower technologies with high optical concentration. Different heat transfer fluids (air, water, thermo-oil, molten salt, steam) and special material issues (selective absorbers, mirror materials, glass etc.) are discussed. The market relevance is discussed.
2) **Solar Thermal Systems Engineering:** Starting from the basic design of a solar thermal system with collector loop, thermal storage, heat exchangers and auxiliary energy source, variations of specific system designs are discussed. An overview over applications and suitable system concepts is given. The knowledge provided guides the students towards an understanding of the interaction of system components and their dynamic system behaviour.

Learning outcomes

After successful completion of this module students should be able to:

- describe the different collector technologies and understand their operation and the important parameters influencing the energy balance.
- understand the concepts of various solar thermal system applications with their peculiarities, advantages and disadvantages.
- design and dimension solar thermal energy systems with respect to demand and economic considerations.
- analyze energy flow and control issues in complex solar thermal systems for an optimized energy production and storage.

4.2.3. Module 3 – Crystalline Silicon Photovoltaics

Module Code	*Module Name*
3	**Crystalline Silicon Photovoltaics**
Courses	
No. 3.1	Feedstock and Crystallization
No. 3.2	Silicon Solar Cells – Structure and Analysis
No. 3.3	Solar Cell Production Technology
No. 3.4	Silicon Module Technology and Reliability
No. 3.5	Hands-on solar Cell Processing

Prerequisites	*Type of Module*	*Rotation*
Module 1	Mandatory	Summer Semester

Type of Courses	*Instruction Language*
Online Lectures / Practical Training	English
Type of examination	*Workload*
Written exam / Laboratory Protocols	250 h (10 ECTS)
Module coordinator	*Additional teachers involved*
Prof. Stefan Glunz	Dr. Martin Schubert, Dr. Ralf Preu, Dr. Harry Wirth, Dr. Jochen Rentsch

Syllabus

In this module the students will get an overview about the value chain of silicon solar cells starting from quartz up to the manufactured module. Students will learn how silicon is produced from quartz and how this silicon is purified, crystallized and cut into wafers. Based on this knowledge, students should be able to develop new and optimized processing sequences and design concepts for silicon solar cells. Finally, students will learn how modules are produced from silicon solar cells and which aspects are particularly important to ensure a long module lifetime.

1) **Feedstock and Crystallization:** This course gives an overview of the most relevant production techniques of crystalline silicon wafers for solar cells. Starting from quartz, purification strategies, crystallization and wafering techniques are presented and discussed.
2) **Silicon Solar Cells:** Structure and Analysis: This course focuses on the fabrication and analysis of crystalline silicon solar cells. The structure of standard industrial silicon solar cells and a rough overview of the production sequence will be discussed. In order to improve the cell performance and thus to reduce the costs of PV electricity, cell characterization and simulation are essential. Based on the achieved understanding of the main power loss mechanisms, we are able to develop new and optimized processing sequences and design concepts for silicon solar cells.
3) **Solar Cell Production Technology:** This course will focus on the fabrication of solar cells from silicon wafers. Students will learn how

	standard industrial cells are produced and what the main loss mechanisms of such cells are. 4) **Silicon Module Technology and Reliability**: This course will focus on interconnection and safe packaging of solar cells into modules to reliably generate electric energy, where the associated module technology has to provide a product capable of operating 20-25 years in the field. 5) **Hands-on Solar Cell Processing:** In this practical training students will work with state of the art inline or batch production tools for the fabrication of crystalline silicon solar cells. Students will learn about specific requirements of each production step. Through processed solar cells students will learn the different impact of each production step on final cell performance.
Learning outcomes	
After successful completion of this module students should be able to: • understand the structure of standard industrial silicon solar cells. • develop an in-depth understanding of all processes within standard silicon solar cell processing. • understand the interaction and technical/economic implications and expected future developments. • optimize solar cell processes and develop new process steps based on a thorough understanding of process steps and their interactions. • conduct and protocol process optimization steps in a production environment. • understand the underlying principles of the most relevant production techniques for solar cell fabrication. • develop and execute complex experimental designs, interpret and present the results • understand the basic processes of module production with a focus on cell interconnection and encapsulation.	

4.3. Elective Modules

4.3.1. General Information

After completing the Mandatory Modules, students have the possibility to specialize in specific topics by choosing from a diverse offer of Elective Modules. Currently three elective topics are offered; each of the topics consist of two modules.

Students should obtain at least 15 ECTS credit points from elective modules and therefor have to choose at least three out of the six available modules. Thereby two of the three chosen modules should belong to the same topic (e.g. Module CM1 and CM2). The third module can be chosen from another topic (e.g. Module PG1 or ST1). Note that while both Modules of the CM topic (CM1 and CM2) can be chosen as the third Module, only PG1 and ST1 can be chosen from the PG and ST topic. Indeed, the Modules PG2 and ST2 can only be chosen if PG1 and ST1 were completed beforehand (mandatory prerequisites).

However, students are free to choose more than 3 elective modules if they are interested in many elective topics.

4.3.2. Topic: Characterization and Modelling (CM)

Module Code	*Module Name*
CM1	**Material and Solar Cell Characterization**
Courses	
N. CM1.1	Material- and Solar Cell Characterization
No. CM1.2	Hands-on Measurement Instrumentation

Prerequisites	*Type of Module*	*Rotation*
Module 1 and 3	Elective	Winter Semester

Type of Courses	*Instruction Language*
Online Lectures / Practical Training	English
Type of examination	*Workload*
Written exam / Laboratory Protocols	125 h (5 ECTS)
Module coordinator	*Additional teachers involved*
Dr. Martin Schubert	Dr. Jonas Haunschild

Syllabus
This module provides a theoretical as well as a practical insight into the characterization techniques used for solar cell characterization. 1) **Material- and Solar Cell Characterization:** This course provides an overview over the most important characterization tools used in material and solar cell characterization. Students gain the knowledge required for

correct selection and use of the methods and get an understanding of the limits of different methods. 2) **Hands-on Measurement Instrumentation:** In this practical training course students will work with state of the art characterization tools for inline- and lab inspection. Students will learn about their specific pros and cons and will learn to combine their results to identify common defects.
Learning outcomes
After successful completion of this module students should be able to: • understand the different material- and devices analysis techniques used in solar cell characterization. • select appropriate measurement techniques methods for the investigation of certain properties and problems of devices. • use the most fundamental measurement techniques for solar cell characterization. • explain measurement results with respect to the underlying processes and properties of solar cells and materials. • conduct and protocol measurements in a lab environment. • interpret, evaluate and present measurement data with different widely used software tools.

Module Code	*Module Name*
CM2	**Device Modelling**
Courses	
No. CM2.1	Numerical Simulation of Solar Cells

Prerequisites	*Type of Module*	*Rotation*
Module 1 and 3	Elective	Winter Semester

Type of Courses	*Instruction Language*
Online Lectures	English
Type of examination	*Workload*
Written exam	125 h (5 ECTS)
Module coordinator	*Additional teachers involved*
Prof. Jürgen Schumacher	None

Syllabus

In this course students will learn how a simulation package for solar cell simulation works. An insight into the numerical techniques to discretize the governing equations to describe solar cells is provided. Different simulation approaches that are frequently applied in practice (locally distributed models, time-dependent solution) are explained.

Learning outcomes

After successful completion of this module students should be able to:

- understand how a simulation package for solar cell simulation works.
- explain the work flow to analyze and predict the performance of different types of solar cells.
- understand the Finite Element Method - this discretization method is frequently used to solve balance equations in practical applications.
- transfer the modeling principle (macro-homogeneous transport equations) to different types of solar cells.
- understand the difference between locally distributed models and time-dependent models; learn application examples for solar cell design and analysis, and PV system simulation..

4.3.3. Topic: Photovoltaic Systems and Grids (PG)

Module Code	*Module Name*
PG1	**Electronics for Photovoltaic Systems**
Courses	
No. PG1.1	Selected Semiconductor Devices
No. PG1.2	Grid Integration and control of PV Systems

Prerequisites	*Type of Module*	*Rotation*
Module D and 1	Elective	Summer Semester

Type of Courses	*Instruction Language*
Seminar / Online lectures	English
Type of examination	*Workload*
Oral presentation / Written exam	150 h (6 ECTS)
Module coordinator	*Additional teachers involved*
Dr. Bernd Wille-Haussmann	Dr. Oliver Höhn

Syllabus

This module provides comprehensive fundamental understanding of different semiconductor devices and on the interaction between PV systems and the power grid.

1) **Selected Semiconductor Devices:** The devices introduced in this seminar are not only used in photovoltaics but usually have applications in nearly all fields of electronics. Additionally, devices complementary to solar cells, such as light emitting diodes are covered.
2) **Grid Integration and control of PV Systems:** This course gives an overview on interactions between PV systems and the power grid. The high share of renewable energies and the decentralized generation and consumption of electricity requires new control strategies. This lecture will give a review on electrical power generation and will help to understand the challenges for distributed energy systems feeding and supporting the power grid.

Learning outcomes

After successful completion of this module students should be able to:

- describe existing semiconductor devices that are used in the context of PV energy conversion.
- explain the physical working principles of the semiconductor devices.
- understand the control strategies and concepts starting from Power Electronics level up to PV Systems.
- describe grid control requirements for generators, consumer and storage facilities in a power grid with a high share of renewable energies.

Module Code	*Module Name*
PG2	**Renewable Energy Systems & Smart Grids**
Courses	
No. PG2.1	Technologies for Renewable Energy Conversion
No. PG2.2	Smart Grids and Energy Autonomous Communities

Prerequisites	*Type of Module*	*Rotation*
Module D, 1 and PG1	Elective	Summer Semester

Type of Courses	*Instruction Language*
Seminar / Online lectures	English
Type of examination	*Workload*
Oral presentation / Written exam	100 h (4 ECTS)
Module coordinator	*Additional teachers involved*
Prof. Christof Wittwer	Dr. Thomas Schlegl

Syllabus

This module gives a wide overview on smart grid and renewable energy systems. Starting with basic issues of energy and efficiency, grid technology will be discussed to balance complex systems with available storage components. In the seminar the students will discuss the advantages and disadvantages of different energy sources.

1) **Technologies for Renewable Energy Conversion:** This seminar provides an overview on different renewable energy technologies, their characteristics, behaviour in energy system, economic and environmental specifications, advantages & disadvantages as well as the market situation.
2) **Smart Grids and Energy Autonomous Communities:** The knowledge provided in this course will be a valuable assistance to the students in order to understand the interaction of several system components as well as their dynamic system behaviour.

Learning outcomes

After successful completion of this module students should be able to:

- describe the different technologies for the use of the various renewable energy sources with their peculiarities, advantages and disadvantages.
- understand and optimize grid connected energy systems.
- understand energy flow in distribution grids with decentralized generation.
- describe and design energy management systems for optimized energy production and storage.

4.3.4. Topic: Solar Cell Technologies (ST)

Module Code	*Module Name*
ST1	**Thin-Film and Concentrator Photovoltaics**
Courses	
No. ST1.1	Inorganic Thin-Film Solar Cells
No. ST1.2	III-V Solar Cells and Concentrator Systems

Prerequisites	*Type of Module*	*Rotation*
Module C and 1	Elective	Winter Semester

Type of Courses	*Instruction Language*
Online lectures	English
Type of examination	*Workload*
Written exam	175 h (7 ECTS)
Module coordinator	*Additional teachers involved*
Prof. Michael Powalla	Dr. Gerald Siefer

Syllabus

This module provides comprehensive fundamental understanding of the basics for Si-based (crystalline, a-Si, a/µc-Si), CIGS, and CdTe thin-film solar cells, modules, and module production.

1) **Inorganic Thin-Film Solar Cells:** This course provides an extensive overview on inorganic thin-film solar cells: physics, materials, growth, production, and characterization. With this information the students will be able to understand the different types of thin-film solar cells, their role in the PV market and the specific applications in which thin-film solar cells excel.
2) **III-V Solar Cells and Concentrator Systems:** This course gives an overview on the field of high concentration photovoltaics. This involves the approach of multi-junction solar cells and issues related to the operation of solar cells under concentrated light. The knowledge gained in this lecture will enable the students to assess present and future novel photovoltaic concepts.

Learning outcomes

After successful completion of this module students should be able to:

- comprehend photovoltaic approaches apart from the standard silicon-based PV.
- evaluate the potentials and challenges for thin-film PV on the global market.
- understand the fundamental physical operation principles of multi-junction solar cells and concentrator systems.
- understand advanced characterization techniques required by III-V multi-junction cells and concentrator modules.

Module Code	*Module Name*
ST2	**Advanced Processing and New Cell Concepts**
Courses	
No. ST2.1	New Concepts for Photovoltaic Energy Conversion
No. ST2.2	Advanced Solar Cell Processing

Prerequisites	*Type of Module*	*Rotation*
Module C, 1 and ST1	Elective	Winter Semester

Type of Courses	*Instruction Language*
Online lectures / Seminar	English
Type of examination	*Workload*
Written exam / Oral presentation	75 h (3 ECTS)
Module coordinator	*Additional teachers involved*
Dr. Uli Würfel	Dr. Martin Heinrich

Syllabus

This module gives a wide overview about existing concepts to overcome the thermodynamical limit for single junction solar cells, the so-called third generation photovoltaics. Different strategies to push efficiency further up will be discussed and it will be shown how they all try to realize one thing: to absorb more photons and/or to convert a higher fraction of the photon energy to electrical energy.

1) **New Concepts for Photovoltaic Energy Conversion:** In this course the students will get a recapitulation of the fundamental processes in the photovoltaic energy conversion. We will then have a close look on different kinds of new types of solar cells and see in how far they differ from conventional solar cells made from inorganic semiconductors. The advantages and the weak points in these emerging technologies will be analysed.
2) **Advanced Solar Cell Processing:** In this seminar new techniques in solar cell production which originate from the related fields of microsystems engineering and nanoscience will be introduced. The processes introduced in this course are likely to concern the PV engineer in an upcoming 10 year period.

Learning outcomes

After successful completion of this module students should be able to:

- understand how far the different kind of new types of solar cells differ from conventional solar cells made from inorganic semiconductors.
- understand the advantages and the weak points in these emerging technologies.
- describe processes which come mainly from the fields of microsystems engineering and nanoscience.
- understand the specific problems of those processes and how to overcome them.

4.4. Research Projects (RP)

4.4.1. General Information

In this module the students complete five Research Projects (RP). During this gradual process they will develop skills in scientific working such as scientific writing and presenting. They get familiar with the standards and methods of scientific working. These skills will be needed for the Master Thesis. In the first semester an introductory lecture will provide first theoretical insights in scientific working. In every following semester the students have to conduct one piece of research as a practical implementation of the concepts presented in the first semester. For each project a scientific report has to be handed in and an oral presentation has to be hold during the campus phase (either in presence or via an online presentation software).

The Research Projects are not graded but the students will get comprehensive and honest feedback for each of their assignments. This feedback gives the possibility to students to continuously improve and to enhance their skills from project to project. Table 4 gives a brief overview about the structure and content of the Research Project Modul following the example of a Broad Track student:

Table 4: Structure and content of the Research Project Module.

RP	Semester	Topic	Supervisor
1a	1st	Online Lecture	Lecturer
1b	2nd	General topic from a list out of the area of renewables	Predefined
2a	3rd	Further specification of the topic chosen in 1b	Predefined
2b	4th	Topic which includes the interpretation of real data	Predefined
3a	5th	Preparation of the Master Thesis	Individual
3b	6th	Presentation of the Master Thesis	Individual

4.4.2. Module R - Research Projects (RP)

Module Code	*Module Name*
R	**Research Projects (RP)**
Courses	
No. R1a	Advanced Research Skills
No. R1b – 3b	Research Projects

Prerequisites	*Type of Module*	*Rotation*
None	Project	Winter and Summer Semester

Type of Courses	*Instruction Language*
Online Lectures / Projects	English

Type of examination	*Workload*
Oral Presentation / Written Paper	125 h (5 ECTS) for each Project
Module coordinator	*Additional teachers involved*
Prof. Thomas Hanemann	None

Syllabus
In this module the student develops skills in scientific working. Beside an introductory lecture in the first semester, the student and the coordinator agree on one or more topics for project work on which the student works throughout Semester 1 to 6. The topic chosen may be related to the student's past or present professional experience or a new topic may be found in agreement with the supervisor. Research Projects provide an early learning environment similar to the master thesis. The topic may or may not lead to a master thesis. The online lecture of this module can be subdivided into three main parts. First *Engineering as Science* defines engineering as an integrated part of the scientific food chain in the conversion from fundamental research into applications. Second *Research Methodology* delivers some tools for scientific working like how to perform literature research or a short introduction into the philosophy of design of experiments (DoE). The third part deals with the elements of *Scientific writing and presentation* covering good scientific practice, correct writing of lab journals, reports, papers, master and PhD-thesis, as well as the successful preparation of scientific talks and posters e.g. for project meetings or conferences.
Learning outcomes
After successful completion of this module students should be able to: • understand the fundamental difference of basic and applied research as well as engineering and the related challenges and exercises. • Understand and apply the *design of experiments* (DoE) method • perform a literature research using established tools like Scopus, Web of knowledge, Google Scholar, Research Gate, and others. • perform patent search using e.g. the European Patent Office. • understand and apply the rules for good scientific practice. • writing a laboratory journal in precise and traceable manner. • transfer the facts in a lab journal in a report or scientific paper. • establish a critical attitude to measured, calculated or simulated data and derived results. • perform a scientific talk of at least 15 min adjusted to a specific target audience. • perform an oral poster presentation (3 min) and the arrangement of a scientific poster.

4.5. Master Thesis (MT)

4.5.1. General Information

The Master Thesis is the final piece of this program – necessary to be awarded with the Master of Science title. It is probably the most demanding and challenging part of the whole program. There are several ways of doing the Master Thesis. But the most recommended one is to come to Freiburg and join one of our high end labs and research groups during this period.

It is absolutely necessary to plan this step in advance. Students should contact the administration team at least 6 months before they plan to start working on their thesis.

The Master Thesis is not depending on the regular semester rhythm. As soon as a student has earned 20 ECTS from the mandatory modules, it is possible to start preparing for and working on the Master Thesis. However, once the thesis has been officially registered it has to be submitted within the next 6 months.

The supervision concept is always individual. Topics from the whole research area of the Fraunhofer ISE and the Faculty of Engineering are possible. Each student will get his individual topic, based on personal preferences and the availability of a suitable supervisor.

If it is not possible for the student to join the laboratories in Freiburg – there are also ways of doing the thesis in distance.

4.5.2. Module M – Master Thesis (MT)

Module Code	*Module Name*
M	**Master Thesis (MT)**
Courses	
No. M	Master Thesis

Prerequisites	*Type of Module*	*Rotation*
At least 20 ECTS out of the mandatory courses	Project	Free

Type of Courses	*Instruction Language*
Scientific Thesis	English
Type of examination	*Workload*
Submission of the Master Thesis	375 h (15 ECTS)
Module coordinator	*Additional teachers involved*
Prof. Dr. L. M. Reindl	First and Second Examiner

Syllabus
The time period for the Master Thesis is defined as 6 months. There are several ways to handle the Master Thesis: • The students can carry out the experimental part of their thesis at the laboratories of the Fraunhofer ISE or the University of Freiburg. To make this possible the students need to come to the laboratory for a period of minimum 3 months. During the rest of the period the students can work at home analysing the measurements carried out at the laboratory and preparing for future measurements. • The students can carry out the Master Thesis at their workplace. To make this possible, it has to be ensured that the company has the required laboratories and equipment to carry out the practical part of the thesis. • Students may work in collaboration with the university or a research institute (like Fraunhofer ISE for example) on a topic in the field of simulation, market research or the like. A thesis with the main focus on management is not accepted. Before starting the thesis the research topic has to be accepted by the Examination Office.
Topic
The choice of topics is individual. It is required that the student contacts the administration of the program at least several months before the start of the Thesis in order to find a fitting topic. • A research topic can be provided / suggested by a lecturer upon student request. Some topics are available at the e-learning platform. • Students who have an own idea for a research topic should contact a lecturer who is willing to supervise the topic. It would be helpful to have an exposé which characterizes the idea of the thesis.
Registration
Before starting to work on the Master Thesis the research topic must be submitted and validated by the Examination Office. This should be done within three months after completion of all modules. The program office will handle the registration in cooperation with the Examination Office. Please contact the program office as soon as you have an idea for a topic and a supervisor. An exposé which provides details about the topic and planed process is highly recommended.
Handling Time
Starting from the date of registration at the Examination Office, students have exactly 6 months' time to complete the Master Thesis. Care has to be given to define a thesis topic that is manageable within that duration.
Supervision
Supervisor of the master thesis could be a lecturer of the program. Supervisors are responsible for the continuous supervision of the whole process of the Master thesis completion and for the subject specific support. The supervisor is usually – but not always – the first examiner. The first examiner has to be a person who is entitled to evaluate examinations at the University of Freiburg (usually a University Professor). The second examiner is not subject to this obligation. If you have any concerns about the first or second examiner, please contact the SEE office for advice.

Language
The thesis has to be submitted in English language. Upon request the thesis may be submitted in a different language, if it is ensured that there is a first examiner/supervisor and a second examiner who are willing to evaluate the thesis in that language. Decision on the request will be made by the Board of Examiners.
Handover Process
The student has to hand over the thesis within the prescribed time limit to the Examination Office. Three printed out and bound versions of the thesis must be submitted. Additionally, a digital version of the thesis has to be submitted. With the handover the student has to confirm, that: • He/ She has carried out the work presented in the thesis on his/ her own. • The parts of the thesis which are not his/ her own work are clearly identified and the source is named. • The thesis - even in parts - has not been used for another examination process. • The printed out copies and the digital version of the thesis are identical. • The thesis has not been published yet.
Presentation
No oral presentation is required after submission of the thesis.

5. Appendix

Lecturers and Tutors

Table 5: Complete list of Lecturers and Tutors of SEE

Name	Institution	Code	Courses
Prof. Dr. Datcheva, Maria	Bulgarian Academy of Sciences	B.1	Mathematical Methods
Dr. Glatthaar, Markus	Fraunhofer ISE	B.2	Physical Methods
Prof. Dr. Glunz, Stefan	Fraunhofer ISE	3.2	Silicon Solar Cells - Structure and Analysis
Prof. Dr. Hanemann, Thomas	University of Freiburg	R	Research Projects
Dr. Haunschild, Jonas	Fraunhofer ISE	CM1.2	Hands-on Measurement Instrumentation
Dr. Heinrich, Martin	University of Freiburg	ST2.2	Advanced Solar Cell Processing
Dr. Höhn, Oliver	Fraunhofer ISE	PG1.1	Selected Semiconductor Devices
Iankov, Dimitre	University of Freiburg	B.1	Mathematical Methods
Iankov, Dimitre	University of Freiburg	CM2	Numerical Simulation of Solar Cells
Kohlep, Maximilian	University of Freiburg	C.1	Semiconductor Devices and ProcessingTechnology
Mahajan, Akshay	Fraunhofer ISE	1.2	Phovoltaic Systems
Prof. Dr. Nebel, Christoph	University of Freiburg	C.2	Solid State and Semiconductor Physics
Niewelt, Tim	Fraunhofer ISE	3	Crystalline Silicon Photovoltaics
Niewelt, Tim	University of Freiburg	CM1.1	Material and Solar Cell Characterization
Prof. Dr. Platzer, Werner	University of Freiburg	2	Solar Thermal Systems
Prof. Dr. Powalla, Michael	ZSW Center for solar energy and hydrogen research	ST1.1	Inorganic Thin-Film Solar Cells

Name	Institution	Code	Courses
Dr. Preu, Ralf	Fraunhofer ISE	3.3	Solar Cell Production Technology
Raymond, Branke	Fraunhofer ISE	2	Solar Thermal Systems
Dr. Reichert, Stefan	Fraunhofer ISE	PG1.2	Grid Integration and Control of PV Systems
Prof. Dr. Reindl, Leonhard	University of Freiburg	M	Master Module
Rémi, Freiche	Fraunhofer ISE	D.1	Electrical Engineering and Power Electronics
Dr. Rentsch, Jochen	Fraunhofer ISE	3.5	Hands-on Solar Cell Processing
Dr. Rüther, Ricardo	Universidade Federal de Santa Catarina	1.2	Phovoltaic Systems
Dr. Schlegl, Thomas	Fraunhofer ISE	PG2.1	Technologies for Renewable Energy Conversion
Dr. Schubert, Martin	Fraunhofer ISE	3.1	Feedstock and Crystallization
Dr. Schubert, Martin	University of Freiburg	CM1.1	Material and Solar Cell Characterization
Prof. Dr. Schumacher, Jürgen	Zurich University of Applied Sciences	CM2	Numerical Simulation of Solar Cells
Sebastian, Illner	University of Freiburg	A.1	The Global Energy Needs in a Nutshell
Dr. Siefer, Gerald	Fraunhofer ISE	ST1.2	III-V Solar Cells and Concentrator Systems
Dr. Stalter, Olivier	Fraunhofer ISE	D.1	Electrical Engineering and Power Electronics
Dr. Wessendorf, Cordula	ZSW Center for solar energy and hydrogen research	ST1.1	Inorganic Thin-Film Solar Cells
Dr. Wirth, Harry	Fraunhofer ISE	3.4	Silicon Module Technology and Reliability
Prof. Dr. Wittwer, Christof	Fraunhofer ISE	PG2.2	Smart Grids and Energy Autonomous Communities
Dr. Würfel, Uli	University of Freiburg	1.1	Solar Cells

Name	Institution	Code	Courses
Dr. Würfel, Uli	University of Freiburg	ST2.1	New Concepts for Photovoltaic Energy Conversion
Prof. Dr. Zacharias, Margit	University of Freiburg	C.1	Semiconductor Devices and ProcessingTechnology