# Solar Energy Engineering – Continuing Education

Certificate Program

UNI FREIBURG

## Module Handbook (Modulhandbuch)

**University of Freiburg**
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in cooperation with
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79110 Freiburg

# Content

# 1 General regulations

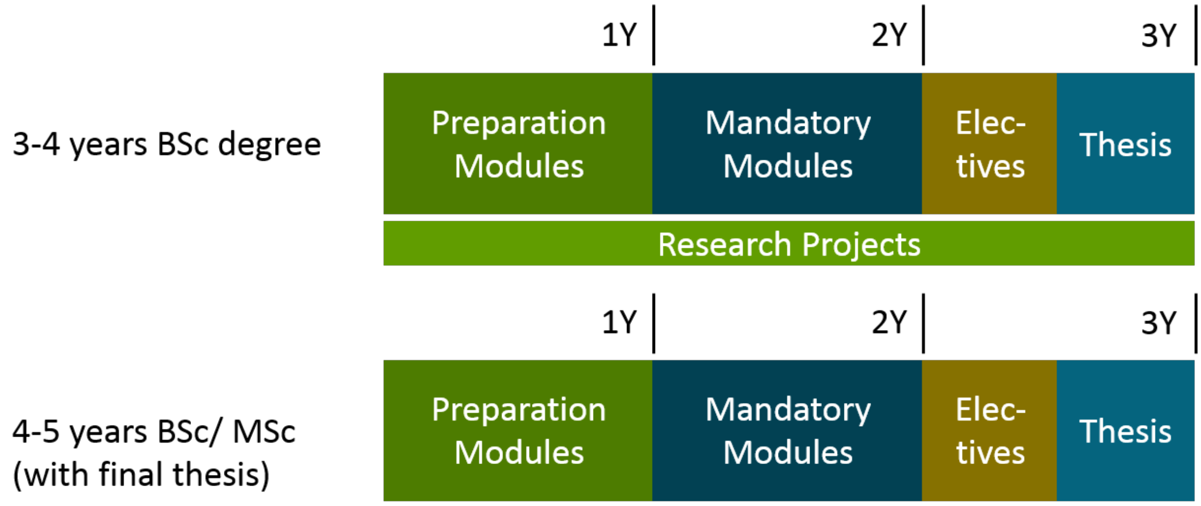
## 1.1 Profile and concept of the Master program

The following academic and examination regulations hold for the postgraduate program Master of Science Solar Energy Engineering at the Albert-Ludwigs-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 provide a highly qualified educational offer, with professional competence starting from 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 possibilities of distance learning and information and communication technology (multimedia learning).

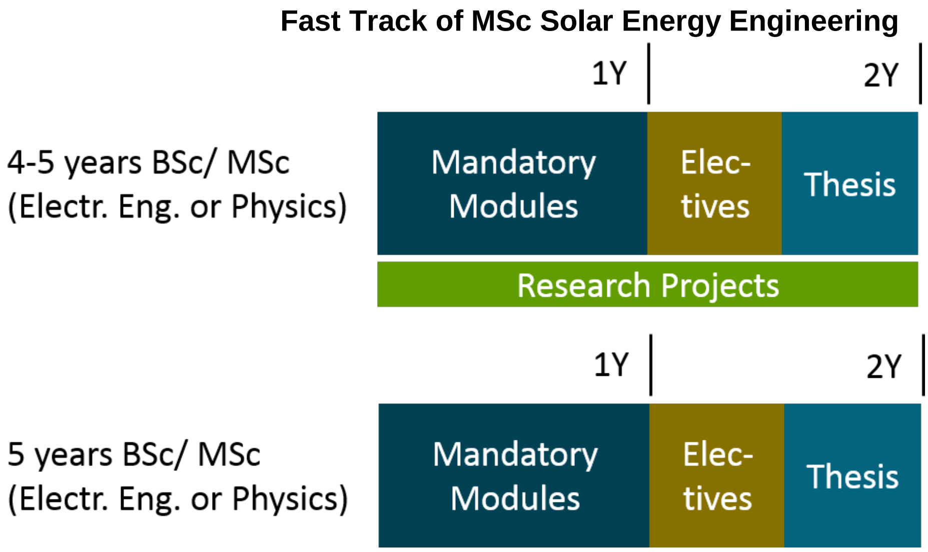
## 1.2 Regular study period and European Credit Transfer and Accumulation System (ECTS)

The postgraduate program M.Sc. Solar Energy Engineering starts in winter semester (October). The courses offered within this program are repeated annually and are Preparation, Mandatory, Elective and Research Project Modules and a Master thesis.
This program takes the students from a Bachelor‘s degree (BSc) to a Master‘s degree in only three years part-time studies (*Broad Track*). Students who already hold a fitting Master‘s degree* (MSc), may shift their career into the solar energy sector in only two years part-time studies (*Fast Track*). Based on the students latest university degree the scope of the Master program is between 60 and 120 ECTS credit points. According to the European Credit Transfer and Accumulation System (ECTS) one ECTS credit point corresponds to an average workload of 25 hours. ECTS credit points are awarded for successfully passing academic achievements, module examinations and the master thesis.

**Broad Track of MSc Solar Energy Engineering**




Students with a BSc degree with 180 ECTS (equivalent with ~3 year's full-time study) with at least 90 ECTS in Math, Physics, and Electrical Engineering are eligible for the broad track of the MSc Solar Energy Engineering program. Students with additional 30 ECTS (in total 210 ECTS) and who wrote a final thesis of at least 15 ECTS during their previous study may be able to skip the research project modules.




Students with a BSc or MSc degree with at least 210 ECTS (equivalent with ~4 year's full-time study) in Physics, Electrical Engineering, or any similar field are eligible for the fast track. Students with a BSc or MSc degree with at least 240 ECTS (equivalent with 5 year's full time study) 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.

## 1.3 Study format

During the study period, students work through the audio lectures, readings and exercise sheets that are assigned at the learning platform. Self-study of the provided reading material supports the understanding. Online meetings are arranged during this self-study phase to ask questions, discuss problems and exercise sheets with lecturers and tutors. 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 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 motivation into a topic and as overview of a specific field within a module. The e-lectures have a length of around 20 mins 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 content. The most relevant and educational developed 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 such that all students from different time zones have a chance to attend and can also be scheduled individual with the lectures or tutors. If it happens that students are not able to attend an online meeting, it is possible to watch a recording of the meeting later.

### 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 send in the solution of 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 are similar to the problems covered in the exercise sheets.

## 1.4 Exam Regulations

In order to pass the written exams associated to the different courses students need to achieve at least the grade 4.0 (sufficient). The written exams take place during the campus phase or simultaneously at a Goethe-Institute or a recognized university. The exam, presentation or lab journal of each part (course/seminar/hands-on) must be passed to finish a module. The final grade is summarized from the single grades of each part, weighted after the arithmetic mean considering the ECTS credit points for each course. Grades are awarded according to the German grading scale (1-5) specified in Table 1.

| ECTS system | German system | Definition |
|---|---|---|
| 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 | non-sufficient/failed |

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

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.
- Self-study and independent preparation and reworking of the lectures and reading materials
- Taking the exams, performing presentation of the seminars and participation at the hands-on course including writing a lab journal during the campus phase.

## 2 Responsible Persons

**Scientific Director:**

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

**Program Coordination:**

Martin Heinrich
Program Coordinator
Albert-Ludwigs-University of Freiburg
Department of Microsystems Engineering – IMTEK
Laboratory for Electrical Instrumentation
Georges-Koehler-Allee 106
79110 Freiburg, Germany

**Teaching Staff**
The teaching staff is composed of professors and lecturers of the Albert-Ludwigs-University, 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)

# 3 Module Overview Solar Energy Engineering - Continuing Education

## 3.1 Preparation Modules

| **Module A** |
|---|
| The Global Energy Needs in a Nutshell |

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|---|---|---|---|
| **Coordinator** | Dr. Winfried Hoffmann | **Module type** | Preparation |
| **Type of courses** | Online Lectures | **Instruction Language** | English |
| **Workload** | 125 h (5 ECTS) | **Semester** | Winter semester |
| **Prerequisites** | none | | |
| **Courses of Module A** | | | |
| Course | No. A1 | The Global Energy Needs in a Nutshell | |

**Module content and description**

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.

**Forms of learning and teaching materials:**

- E-lectures and associated reading material that is assigned in each e-lecture.
- Online meetings and forum to ask questions and discuss issues.
- Exercise sheets associated to each lecture block.

**Requirements for the awarding of credit points:**

- Submitting the written paper at the end of the course.

## Module B

# Fundamentals of Physics and Engineering

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|---|---|---|---|
| **Coordinator** | Prof. Maria Datcheva | **Module type** | Preparation |
| **Type of courses** | Online Lectures | **Instruction Language** | English |
| **Workload** | 250 h (10 ECTS) | **Semester** | Winter semester |
| **Prerequisites** | none | | |
| **Courses of Module B** | | | |
| Course | No. B1 | Mathematical Methods | |
| Course | No. B2 | Physical Methods | |

**Module content and description**

This module covers the fundamentals of mathematical and physical methods and gives a basic introduction into electrical engineering in order to prepare the students for the contents of the mandatory modules.

**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.

**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.

**Forms of learning and teaching materials:**

- E-lectures and associated reading material that is assigned in each e-lecture.
- Online meetings and forum to ask questions and discuss issues.
- Exercise sheets associated to each lecture block.

**Requirements for the awarding of credit points:**

- Passing the 150 min written exams during the campus phase.

| Module C |
| --- |
| Fundamentals of Semiconductor |

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| --- | --- | --- | --- | --- |
| **Coordinator** | Prof. Margit Zacharias | | **Module type** | Preparation |
| **Type of courses** | Online Lectures | | **Instruction Language** | English |
| **Workload** | 300 h (12 ECTS) | | **Semester** | Summer semester |
| **Prerequisites** | none | | | |
| **Courses of Module C** | | | | |
| Course | No. C1 | Semiconductor Devices and Processing Technology | | |
| Course | No. C2 | Solid State and Semiconductor Physics | | |

**Module content and description**

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.

**Semiconductor Devices and Processing Technology:** This course provides an introduction to the fundamental processes that are required to produce semiconductor devices. Basics in semiconductor physics and devices will be developed.

**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.

**Forms of learning and teaching materials:**

- E-lectures and associated reading material that is assigned in each e-lecture.
- Online meetings and forum to ask questions and discuss issues.
- Exercise sheets associated to each lecture block.

**Requirements for the awarding of credit points:**

Passing the 180 min written exams during the campus phase.

**Module D**

# Electrical Engineering and Power Electronics

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|---|---|---|---|
| **Coordinator** | Dr. Olivier Stalter | **Module type** | Preparatory |
| **Type of courses** | Online Lectures | **Instruction Language** | English |
| **Workload** | 75 h (3 ECTS) | **Semester** | Winter semester |
| **Prerequisites** | Modul B | | |
| **Courses of Module D** | | | |
| Course | No. D1 | Electrical Engineering and Power Electronics | |

**Module content and description**

This module gives a basic introduction into electrical engineering in order to prepare the students for the contents of the mandatory modules.

**Electrical Engineering and Power Electronics:** This course introduces 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.

Forms of learning and teaching materials:

- E-lectures and associated reading material that is assigned in each e-lecture.
- Online meetings and forum to ask questions and discuss issues.
- Exercise sheets associated to each lecture block.

Requirements for the awarding of credit points:

- Passing the 45 min written exams during the campus phase.

## 3.2 Research Projects

| Module RP |
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| Research Projects |

| Coordinator | Prof. Thomas Hanemann | Module type | Project |
|---|---|---|---|
| Type of courses | Online Lectures / Projects | Instruction Language | English |
| Workload | 125 h (5 ECTS), each | Semester | Winter semester and summer semester |
| Prerequisites | none | | |
| **Courses of Module C** | | | |
| Course | No. RP 1a<br>No. RP 1b - 3b | Advanced Research Skills<br>Research Projects | |

**Module content and description**

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 through 6. The topic may be chosen from the student's past or present professional experience or a new topic may be found in agreement with the coordinator. 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 e.g. for project meetings or conferences.

**Learning outcomes**

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

- understand that engineering is a part of science.
- perform a literature research using established tools like Scopus, Web of Science or Research Gate.
- apply the rules for good scientific practice.
- writing a laboratory journal in correct manner.
- establish a critical attitude to measured, calculated or simulated data and results
- transfer the facts in a lab journal in a report or scientific paper.
- perform a scientific talk of at least 15 min adjusted to a specific target audience.

**Forms of learning and teaching materials:**

- E-lectures and associated reading material that is assigned in each e-lecture.
- Online meetings and forum to ask questions and discuss issues.
- Research work.

**Requirements for the awarding of credit points:**

- Presenting a 15 min talk during the campus phase or a scientific poster.
- Writing a short scientific paper (length 3-6 pages).

## 3.3 Mandatory Modules

| **Module 1** |
|---|
| Solar Cells and Photovoltaic Systems |

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| **Coordinator** | Prof. Stefan Glunz | **Module type** | Mandatory |
| **Type of courses** | Online Lectures | **Instruction Language** | English |
| **Workload** | 250 h (10 ECTS) | **Semester** | Winter semester |
| **Prerequisites** | Module A, B, C and D (i.e. Preparation Courses) | | |
| **Courses of Module 1** | | | |
| Course | No. 1.1 | Solar Cells | |
| Course | No. 1.2 | Photovoltaic Systems | |

**Module content and description**

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

**Solar Cells:** This course builds the base 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.

**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.

**Forms of learning and teaching materials:**

- E-lectures and associated reading material that is assigned in each e-lecture
- Online meetings and forum to ask questions and discuss issues
- Exercise sheets associated to each lecture block

**Requirements for the awarding of credit points:**

- Passing the 150 min written exams during the campus phase.

| Module 2 |
| --- |
| Solar Thermal Systems |

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| **Coordinator** | Prof. Werner Platzer | **Module type** | Mandatory |
| **Type of courses** | Online Lectures | **Instruction Language** | English |
| **Workload** | 250 h (10 ECTS) | **Semester** | Winter semester |
| **Prerequisites** | Module A, B, C and D (i.e. Preparation Courses) | | |
| **Courses of Module 2** | | | |
| Course | No. 2.1 | Fundamentals of Solar Thermal Collectors | |
| Course | No. 2.2 | Solar Thermal Systems Engineering | |

Module content and description

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 will be presented. Here the complex systems for different applications ranging from solar water heating to process heat for industry to solar thermal power production will be described.

**Fundamentals of Solar Thermal Collectors:**

The course provides an extensive overview over optical and thermal characteristics of basically all solar thermal collector technologies, from flat-plate collectors to solar tower technologies with high optical concentration. The different heat transfer fluids (air, water, thermo-oil, molten salt, steam) as well as special material issues (selective absorbers, mirror materials, glass etc.) will be discussed. The market relevance will be presented.

**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 e.g. in solar heating will be discussed. An overview over applications and suitable system concepts will be given. The knowledge provided will be a valuable assistance to the students in order to understand the interaction of system components and their dynamic system behavior.

**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.

Forms of learning and teaching materials:

- E-lecture and associated reading materials that are assigned for each lecture
- Exercise sheets to practically learn quantification of energy flows and dimensioning of systems
- Online Meeting and forum to ask questions and discuss issues

Requirements for the awarding of credit points:

- Presentation (15 min) and paper (4-5 p.) about the topic assigned to the students at the beginning of the semester
- Passing the 150 min written exam during the campus phase

| Module 3 |
|---|
| Crystalline Silicon Photovoltaics |

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| **Coordinator** | Prof. Stefan Glunz | **Module type** | Mandatory |
| **Type of courses** | Online Lectures / Practical training | **Instruction Language** | English |
| **Workload** | 250 h (10 ECTS) | **Semester** | Summer semester |
| **Prerequisites** | Module 1 | | |
| **Courses of Module 4** | | | |
| Course | No. 3.1 | Feedstock and Crystallization | |
| Course | No. 3.2 | Silicon Solar Cells – Structure and Analysis | |
| Course | No. 3.3 | Solar Cell Production Technology | |
| Course | No. 3.4 | Hands-on solar Cell Processing | |
| Course | No. 3.5 | Silicon Module Technology and Reliability | |

**Module content and description**

In this module the students will get an overview about the value chain of silicon solar cells starting from quartz up to the finished 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.

**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.

**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.

**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.

**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.

**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.

**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.

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|---|
| • optimize solar cell processes and develop new process steps based on a thorough understanding of process steps and their interactions.<br>• to conduct and protocol process optimization steps in a production environment.<br>• understand the underlying principles of the most relevant production techniques for solar cell fabrication.<br>• develop and execute complex experimental designs, interpret and present the results<br>• understand the basic processes of module production with a focus on cell interconnection and encapsulation. |
| **Forms of learning and teaching materials:** |
| • E-lectures and associated reading material that is assigned in each e-lecture.<br>• Online meetings and forum to ask questions and discuss issues.<br>• Exercise sheets associated to each lecture block.<br>• Material available on Campus Online for preparation for practical training during the campus phase. |
| **Requirements for the awarding of credit points:** |
| • Passing the 150 min written exams during the campus phase.<br>• Completing all experiments during the campus phase.<br>• Submission of experiment protocol/ lab journal (theoretical and practical part). |

## 3.4 Electives

### 3.4.1 Topic: Characterization and Modelling

| **Module CM1** |
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| Material and Solar Cell Characterization |

| **Coordinator** | Dr. Martin Kasemann | **Module type** | Mandatory |
| --- | --- | --- | --- |
| **Type of courses** | Online Lectures / Practical training | **Instruction Language** | English |
| **Workload** | 125 h (5 ECTS) | **Semester** | Winter semester |
| **Prerequisites** | Module 1 | | |
| **Courses of Module 2** | | | |
| Course | No. CM1.1 | Material- and Solar Cell Characterization | |
| Course | No. CM1.2 | Hands-on Measurement Instrumentation | |

**Module content and description**

This module provides a theoretical as well as a practical insight into the characterization techniques used for solar cell characterization. For a detailed overview please look up the syllabus in the course description.

**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.

**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.

**Forms of learning and teaching materials:**

- E-lectures and associated reading material that is assigned in each e-lecture.
- Exercise sheets associated to each lecture block.
- Abstract for each experiment, describing the tool and its application for quality control.
- Articles from literature to find out about the physical fundamentals.
- Online meetings and forum to ask questions and discuss issues.

**Requirements for the awarding of credit points:**

- Passing the 45 min written exams during the campus phase.
- Completing all experiments during the campus phase.
- Submission of experiment protocol/ lab journal (theoretical and practical part).

| Module CM2 |
|---|
| Device Modeling and Advanced Characterization |

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|---|---|---|---|
| **Coordinator** | Prof. Jürgen Schumacher | **Module type** | Elective |
| **Type of courses** | Online Lectures | **Instruction Language** | English |
| **Workload** | 125 h (5 ECTS) | **Semester** | Winter semester |
| **Prerequisites** | Modules 1 and CM1 | | |
| **Courses of Module 7** | | | |
| Course | No. CM2.1 | Numerical Simulation of Solar Cells | |
| Course | No. CM2.2 | Advanced Material and Solar Cell Characterization | |

**Module content and description**

This module provides an advanced understanding of multi-dimensional effects in solar cell and material characterization. Students will also learn how a simulation package for solar cell simulation works, by providing an insight into the numerical techniques to discretize the governing equations to describe solar cells.

**Numerical Simulation of Solar Cells:** This course provides an insight into the numerical techniques to discretize the governing equations to describe solar cells. Different simulation approaches that are frequently applied in practice (locally distributed models, time-dependent solution) are explained.

**Advanced Material and Solar Cell Characterization:** This course provides an advanced understanding of multi-dimensional effects in solar cell and material characterization. The students are introduced to advanced characterization tools for spatially resolved solar cell characterization and the related physical models for measurement interpretation.

**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.
- understand the multi-dimensional effects in solar cell and material characterization.

**Forms of learning and teaching materials:**

- E-lectures and associated reading material that is assigned in each e-lecture.
- Online meetings and forum to ask questions and discuss issues.
- Exercise sheets associated to each lecture block.

**Requirements for the awarding of credit points:**

- Passing the 45 min written exams during the campus phase.

### 3.4.2 Topic: Photovoltaic Systems and Grids

| Module PG1 |
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| Electronics for Photovoltaic Systems |

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|---|---|---|---|
| **Coordinator** | Prof. Eicke Weber | **Module type** | Mandatory |
| **Type of courses** | Seminar / Online Lectures | **Instruction Language** | English |
| **Workload** | 150 h (6 ECTS) | **Semester** | Summer semester |
| **Prerequisites** | Module 1 | | |
| **Courses of Module 3** | | | |
| Course | No. PG1.1 | Selected Semiconductor Devices | |
| Course | No. PG1.2 | Grid Integration and control of PV Systems | |

**Module content and description**

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

**Forms of learning and teaching materials:**

- Discussion of presentation topics in small groups in the virtual classroom.
- E-lectures and associated reading material that is assigned in each e-lecture.
- Online meetings and forum to ask questions and discuss issues.
- Exercise sheets associated to each lecture block.

**Requirements for the awarding of credit points:**

- Presentation (15 min) and paper (4-5 p.) about the topic assigned to you at the beginning of the semester.
- Passing the 60 min written exams during the campus phase.

| Module PG2 |
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| Energy Systems |

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| **Coordinator** | Prof. Christof Wittwer | **Module type** | | Elective |
| **Type of courses** | Seminar/ Online Lectures | **Instruction Language** | | English |
| **Workload** | 100 h (4 ECTS) | **Semester** | Summer semester | |
| **Prerequisites** | Module 1 and PG1 | | | |
| **Courses of Module 6** | | | | |
| Course | No. PG2.1 | Technologies for Renewable Energy Conversion | | |
| Course | No. PG2.2 | Smart Grids and Energy Autonomous Communities | | |

**Module content and description**

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.

**Technologies for Renewable Energy Conversion:** This seminar provides an extensive overview on the integration of different renewable energy systems into the electricity grid and the optimization of the combination of different renewable energy conversion techniques with respect to power demand satisfaction, operating security and safety and economic issues.

**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 behavior.

**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.

**Forms of learning and teaching materials:**

- E-lectures and associated reading material that is assigned in each e-lecture.
- Online meetings and forum to ask questions and discuss issues.
- Exercise sheets associated to each lecture block.

**Requirements for the awarding of credit points:**

- Presentation (15 min) and paper (4-5 p.) about the topic assigned to you at the beginning of the semester.
- Passing the 30 min written exams during the campus phase.

### 3.4.3 Topic: Solar Cell Technologies

| Module ST1 |
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| Thin-Film and Concentrator Photovoltaics |

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| **Coordinator** | Prof. Michael Powalla | **Module type** | Mandatory |
| **Type of courses** | Online Lectures | **Instruction Language** | English |
| **Workload** | 175 h (7 ECTS) | **Semester** | Winter semester |
| **Prerequisites** | Module 1 | | |
| **Courses of Module 5** | | | |
| Course | No. ST1.1 | Inorganic Thin-Film Solar Cells | |
| Course | No. ST1.2 | III-V Solar Cells and Concentrator Systems | |

**Module content and description**

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.

**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.

**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.

**Forms of learning and teaching materials:**

- E-lectures and associated reading material that is assigned in each e-lecture.
- Online meetings and forum to ask questions and discuss issues.
- Exercise sheets associated to each lecture block.

**Requirements for the awarding of credit points:**

- Passing the 105 min written exams during the campus phase.

| **Module ST2** |
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| Advanced Processing and New Cell Concepts |

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| **Coordinator** | Uli Würfel | **Module type** | | Elective |
| **Type of courses** | Online Lectures / Seminar | **Instruction Language** | | English |
| **Workload** | 75 h (3 ECTS) | **Semester** | Winter semester | |
| **Prerequisites** | Module 1 and ST1 | | | |
| **Courses of Module 8** | | | | |
| Course | No. ST2.1 | New Concepts for Photovoltaic Energy Conversion | | |
| Course | No. ST2.2 | Advanced Solar Cell Processing | | |

**Module content and description**

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.

**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 analyzed.

**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.

**Forms of learning and teaching materials:**

- E-lectures and associated reading material that is assigned in each e-lecture.
- Online meetings and forum to ask questions and discuss issues.
- Exercise sheets associated to each lecture block.

**Requirements for the awarding of credit points:**

- Presentation (20 min) and paper (4-5 p.) about the topic assigned to you at the beginning of the semester.
- Passing the 30 min written exams during the campus phase.

## 3.5 Master Thesis

| **Module Master Thesis** |
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| Master Thesis |

| **Coordinator** | Prof. Leonhard Reindl | **Module type** | mandatory |
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| **Type of courses** | Thesis | **Language** | English |
| **Workload** | 375 h (15 ECTS) | **Semester** | |
| **Prerequisites** | At least 20 ECTS points out of the mandatory courses | | |

**Content**

There are several ways to handle the Master Thesis:

- 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 to carry out the practical part of the thesis. Before starting the thesis the research topic has to be accepted by the Examination Office.
- 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.
- 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 3-6 times with duration of 1-2 weeks each time. During the rest of the period the students can work at home evaluating the measurements carried out at the laboratory and preparing for future measurements.

**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 proposed at 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 if you have an idea for a topic and a supervisor.

**Handling Time**

Starting from the date of registration at the examination office, the handling time for the master thesis has duration of 6 months. The topic of the thesis has to be manageable within that duration.

**Supervisor**

Supervisor of the master thesis could be a lecturer of the program. The primary reviewer has to be a person who is entitled to evaluate examinations at the University of Freiburg (usually a University Professor). If you have any concerns about the primary reviewer, 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 primary reviewer and a

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| | supervisor who are willing to evaluate the thesis in that language. Decision on the request will be done by the Board of Examiners. |
| **Handover Process** | |
| The student has to handover 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 softcopy of the thesis has to be submitted. With the handover the student has to ensure, that:<br>• He / She has carried out the work presented in the thesis on his / her own.<br>• The parts of the thesis which are not his /her own work are clearly identified and the source is named.<br>• The thesis - even in parts – has not been used for another examination process.<br>• The printed out versions and the soft copy of the thesis are identical.<br>• The thesis has not been published yet. | |
| **Presentation** | |
| | No oral presentation is required after submission of the printed out versions of the thesis. |

## Attachment: List of supporting lectures and tutors

| Name | First Name | Institution | Courses |
|---|---|---|---|
| Datcheva | Maria | Bulgarian Academy of Sciences | Mathematical Methods |
| Glatthaar | Markus | Fraunhofer ISE | Physical Methods |
| Glunz | Stefan | Fraunhofer ISE | Silicon Solar Cells - Structure and Analysis |
| Gutsch | Sebastian | University of Freiburg | Semiconductor Devices and ProcessingTechnology |
| Hanemann | Thomas | University of Freiburg | Research Projects |
| Haunschild | Jonas | Fraunhofer ISE | Hands-on Measurement Instrumentation |
| Hildebrandt | Nicolai | Fraunhofer ISE | Electrical Engineering and Power Electronics |
| Heinrich | Martin | University of Freiburg | Advanced Solar Cell Processing (Seminar) |
| Hoffmann | Winfried | Applied Solar Expertise | The Global Energy Needs in a Nutshell |
| Höhn | Oliver | Fraunhofer ISE | Selected Semiconductor Devices (Seminar) |
| Iankov | Dimitre | University of Freiburg | Numerical Simulation of Solar Cells |
| Kasemann | Martin | University of Freiburg | Material and Solar Cell Characterization |
| Mahajan | Akshay | Fraunhofer ISE | Phovoltaic Systems |
| Michl | Bernhard | Fraunhofer ISE | Crystalline Silicon Photovoltaics |
| Nebel | Christoph | University of Freiburg | Solid State and Semiconductor Physics |
| Platzer | Werner | University of Freiburg | Solar Thermal Systems |
| Powalla | Michael | ZSW Center for solar energy and hydrogen research | Inorganic Thin-Film Solar Cells |
| Preu | Ralf | Fraunhofer ISE | Solar Cell Production Technology |
| Reichert | Stefan | Fraunhofer ISE | Grid Integration and Control of PV Systems |
| Rentsch | Jochen | Fraunhofer ISE | Hands-on Solar Cell Processing |
| Schlegl | Thomas | Fraunhofer ISE | Technologies for Renewable Energy Conversion (Seminar) |
| Schubert | Martin | Fraunhofer ISE | Feedstock and Crystallization |
| Schumacher | Jürgen | Zurich University of Applied Sciences | Numerical Simulation of Solar Cells |
| Siefer | Gerald | Fraunhofer ISE | III-V Solar Cells and Concentrator Systems |
| Stalter | Olivier | Fraunhofer ISE | Phovoltaic Systems |
| Wessendorf | Cordula | ZSW Center for solar energy and hydrogen research | Inorganic Thin-Film Solar Cells |
| Wirth | Harry | Fraunhofer ISE | Silicon Module Technology and Reliability |
| Wittwer | Christof | Fraunhofer ISE | Smart Grids and Energy Autonomous Communities |
| Würfel | Uli | University of Freiburg | New Concepts for Photovoltaic Energy Conversion |
| Zacharias | Margit | University of Freiburg | Semiconductor Devices and ProcessingTechnology |
| Zimmermann | Birger | University of Freiburg | New Concepts for Photovoltaic Energy Conversion |