Module Catalogue

Master of Science (M. Sc.) Sustainable Systems Engineering

Subject-specific Examination Regulations 2016

Institut für Nachhaltige Technische Systeme
Technische Fakultät
Albert-Ludwigs-Universität Freiburg

14 August 2019

UNI FREIBURG

INATECH

Inhalt

The international Master's program Sustainable Systems Engineering

Science and engineering are basic tools to achieve sustainable development, not only in technology, but also in domains such as ecology, economics and society.
The international Master's program Sustainable Systems Engineering (SSE) provides in-depth engineering skills in sustainable materials, sustainable energy systems, and resilience. Complementing interdisciplinary knowledge in natural resources and climate change, as well as sustainable economy, technology and society is also taught during the two-year-program.

The Master's program in SSE is designed for highly qualified graduate students holding a Bachelor‘s degree in engineering or science. SSE students will have the opportunity to:

- be involved in cutting-edge research with internationally renowned professors,
- benefit from state-of-the-art equipment on a modern campus and pioneering laboratories at partner institutes,
- benefit from a European campus (www.eucor-uni.org), and
- live in one of Germany’s most appealing and green cities.

The SSE Master's is designed to prepare graduates in particular for a further career in research. Moreover, highly qualified SSE graduates will satisfy today’s needs of

- the conventional and renewable energy industry,
- supply companies, manufacturers and operators active in fields like mobility, energy, infrastructure planning, environmental engineering, risk & resilience, and (raw) materials.

Department of Sustainable Systems Engineering (INATECH)

The Department of Sustainable Systems Engineering (Institut für Nachhaltige Technische Systeme - INATECH) was founded by the University of Freiburg in October 2015. The aim was to connect teaching and research in the field of sustainable systems and to complement the university with an engineering research facility for research in sustainability. Together with the Department of Microsystems Engineering (IMTEK) and the Department of Computer Science (IIF) it builds the Faculty of Engineering.

In cooperation with the Fraunhofer Institutes in Freiburg, the following research emphases were conceptualized:

- Sustainable Materials - which can be produced and applied in an energy and resource friendly way.
- Energy Systems - which can provide a reliable and efficient supply and storage of renewable energies.
- Resilience - which can secure the robustness and adaptability of systems towards environmental disasters and climate change.

Examination regulations and module catalogue

This module catalogue has been compiled according to the 2016 examination regulations (Prüfungsordnung) for the study program Master of Science in Sustainable Systems Engineering. Examination regulations define the requirements for a specific degree. Usually the requirements consist of a mandatory and an elective section. These sections in itself are divided into compulsory or elective modules. A module is a self-contained unit within a scientific topic or area that is defined by specific learning goals. Modules may consist of one or more courses, course-based assessments and coursework – depending on the learning objectives. A course is the smallest unit described in this catalogue. There are different types of courses including lectures, exercises, laboratory courses and seminars.

This module catalogue describes the modules that constitute the curriculum of the master's program Sustainable Systems Engineering (SSE). Module descriptions clarify elements such as title, learning objectives, course content, name of the offering institution/professor, type of assessment, and – importantly – how many ECTS credit points according to the „European Credit Transfer and Accumulation System" (short: ECTS system) the student will earn when completing the module successfully. These credit points define the associated work load for the student. One credit point is equivalent to a work load of 30 hours. The recommended number of ECTS points to be completed per term is 30. The ECTS credits usually define the weighting of a module within the whole study program and its impact on the final grade (similar to grade point average (GPA)) – however, there are exemptions; these will be mentioned in the module description, too, if any. Students of the master's program SSE have to complete 120 ECTS credit points in total in order to earn their degree. This usually requires four terms or two years, respectively.

More information about the examination regulations of the master's program can be found at on INATECH's website.

Structure and curriculum of the Master of Science program

The master's program is divided into the following two main sections:

- Compulsory Modules with 65 ECTS (mandatory section)
- Elective Modules with 55 ECTS (elective section)

The **mandatory section** consists of eight compulsory modules with a total of 65 ECTS credits, which all must be completed.

- Fundamentals of Resilience
- Material Life Cycles
- Computational Materials' Engineering
- Solar Energy
- Energy Storage
- Control and Integration of Grids

- Master's Project
- Master's Thesis and Colloquium

The **elective section** of the SSE is divided into a technical and a non-technical specialization area with a total of 55 ECTS credits.

The Technical Specialization area is sub-divided into four different concentration areas:

- Energy Systems
- Information Processing Technologies
- Sustainable Materials
- Resilience Engineering

Within the concentration areas a variety of modules are offered – these can be originating from INATECH, but also from other departments and faculties (such as IMTEK; IIF, or Physics). Due to their interdisciplinary content, a few modules are applicable to more than one concentration area and are therefore mentioned in both areas; in such cases, students must decide in which area the module shall be credited.

Students must select a minimum of two concentration areas, and in each of these two areas a minimum of 10 ECTS points must be completed. In addition, students must complete two modules with a total amount of 10 ECTS from the following three modules.

- Design and Monitoring of Large Infrastructures
- Power Electronic Circuits and Devices
- Security and Privacy in Resilient Systems

The non-technical specialization is called "Interdisciplinary Profile". In the Interdisciplinary Profile students must complete a minimum of 10 ECTS points. Students can select modules mentioned in this handbook but also modules from all over the University for their Interdisciplinary Profile.

The remaining 15 ECTS (to complete the 120 ECTS for the master's program) can be selected from either the technical or the non-technical specialization areas (see the study plan on the next page).

In the first semester six compulsory modules will get everyone on the same technical level. From the second semester on, students start concentrating on their favorite research field and select several interdisciplinary modules to enhance their holistic societal and scientific understanding. The following illustration shows the recommended curriculum as it is expected to lead to a balanced workload. It also ensures consistency in content since some modules build on the skills and knowledge gained in others.

Recommended STUDY PLAN for Master of Science *Sustainable Systems Engineering*

INATECH
DEPARTMENT OF SUSTAINABLE SYSTEMS ENGINEERING

status as of 07/2018; changes reserved

	Term 1	Term 2	Term 3	Term 4	
	Compulsory modules (30 ECTS) - Energy Storage - Control and Integration of Grids - Computational Materials' Engineering - Fundamentals of Resilience - Material Life Cycles (MLC) - Solar Energy	**Compulsory elective modules** (10 ECTS, two out of three) - Monitoring and Design of Large Infrastructures - Power Electronic Circuits and Devices - Security and Privacy in Resilient Systems	**Master's Project** (5 ECTS)	**Master's Thesis and Colloquium** (30 ECTS)	
		Technical Specialization (20 - 35 ECTS, min. 10 ECTS each in two of the four areas) - Energy Systems - Information Processing - Sustainable Materials - Resilience Engineering			
		Interdisciplinary Profile (10 - 25 ECTS)			
ECTS	**30**	**30**	**30**	**30**	**120**

Info: ECTS is a standard for comparing the study attainment and performance of students of higher education across the European Union and other collaborating European countries. For successfully completed studies in the *Sustainable Systems Engineering* master's program, 120 ECTS credits are awarded. One ECTS credit equals on average 30 hours of workload.

For more information see the *Examination Regulations* of the program, they set the legal framework for the studies.
The available modules within these sections and the associated classes as well as their admission requirements are listed and described in detail in the respective module handbook.

Overview of compulsory and elective modules

Modules offered by INATECH, IMTEK or IIF (Faculty of Engineering) are available for registration in HISinOne. Usually there is no limitation of spots in modules from IMTEK and IIF; however, there are a few exceptions with limited capacity. INATECH also offers a few modules with limited capacity. For example, the PV lab has 20 spots available every semester, but such limitation is valid for other courses, too (check out the module description). These limited seats are allocated based on a lottery (NOT first-come-first-serve!) carried out by the HISinOne system. This lottery is objective and cannot and will not be influenced by staff members. It is therefore highly recommended to also have a back-up plan since students cannot count on getting a seat in such a course! There is no legal right to get a seat in a specific course/module.
By clicking on the page number given next to the module name, you will be directed to the module description.

1. Mandatory section

Compulsory modules

- Energy Storage (p.16)
- Control and Integration of Grids (p.25)
- Computational Materials' Engineering (p.27)
- Fundamentals of Resilience (p.18)
- Material Life Cycles (p.23)
- Solar Energy (p.29)

- Master Project (p.21)
- Master Thesis and Colloquium (p.20)

2. Elective section

Compulsory elective modules

- Design and Monitoring of Large Infrastructures (p.50)
- Power Electronic Circuits and Devices (p.31)
- Security and Privacy in Resilient Systems (p.179)

} must select 2 out of 3

Technical Specialization Areas

Energy Systems

- Characterization of solar cells: From feedstock quality to final cell efficiency (p.176)
- Compiler Construction (p.40)
- Electrochemical energy applications (p.62)
- Electrochemical Energy Applications: Batteries (IMTEK)
- Electrochemical energy applications: Li-ion batteries and fuel cells (p.60)
- Electromobility (p.66)
- Emerging and Future Photovoltaic Technology Options (p.185)
- Energy Economics (p.74)
- Energy in Buildings: energy demand and building physics (p.70)
- Energy in Buildings: components and systems for energy supply (p.72)

- Functional Safety: Active Resilience (p.82)
- Industrial manufacturing and application of solar cells and modules (p.91)
- Multi-junction solar cell technology and concentrator PV (p.187)
- Nanotechnology (IMTEK)
- Operations Research for Energy Systems (p.152)
- Photovoltaic Energy Conversion (p.162)
- Photovoltaic Laboratory (p.164)
- Power Electronics: Devices and Concepts (p.115)
- Power Electronics for E-Mobility (p.111)
- Power Electronics for Photovoltaics and Wind Energy (p.113)
- Python for Energy System and Sustainability Analysis (p.168)
- Quantification of Resilience (p.170)
- RF- and Microwave Devices and Circuits (p.172)
- RF- and Microwave Design Course (p.174)
- Systems theory and automatic control II (p.183)
- Thermoelectric (p.191)
- Thermoelektrik und thermische Messtechnik (IMTEK)
- Wind energy systems (p.199)

Sustainable Materials

- Adhesive Bonding (p.98)
- Bioinspired functional materials (p.34)
- Bionic Sensors (p.36)
- Bionic Sensors Lab (p.38)
- Ceramic Materials for Microsystems (p.96)
- Composite materials (p.85)
- Contact, Adhesion, Friction (p.101)
- Continuum mechanics I with exercises (p.103)
- Continuum mechanics II with exercises (p.105)
- Disposable sensors (p.52)
- Dynamics of Materials: Material Characterization (p.197)
- Electrochemical energy applications: Li-ion batteries and fuel cells (p.60)
- Electrochemical Methods for Engineers (p.64)
- Engineering of Functional Materials (p.76)
- Industrial manufacturing and application of solar cells and modules (p.91)
- Lattice Gas Methods (p.109)
- Life Cycle Management (p.117)
- Lightweight Design and Materials (p.119)
- Materials Selection and Sustainable Development für Mechanical Engineering (p.122)
- Mechanical Properties and Degradation Mechanisms (p.125)
- Methods of Material Analysis (p.127)
- Molecular Statics and Molecular Dynamics (p.133)
- Nachhaltiges Energie- und Stoffstrommanagement (UNR)
- Nanomaterials – Laboratory (p.139)
- Nanomaterials – Lecture (p.138)
- Optical Properties of Micro and Nano Structures (p.156)
- Pape it lab: make (bio)analytical devices out of paper (p.158)
- Particle Methods in Engineering (p.140)
- Particle Simulation Methods (p.160)
- Surface Analysis (p.149)
- Surface Analysis Lab (p.150)

- Theory and Modeling of Materials (p.189)

Resilience Engineering

- Bionic Sensors (dtf)
- Bionic Sensors Laboratory (dtf)
- Continuum mechanics I with exercises (p.103)
- Continuum mechanics II with exercises (p.105)
- Dynamics of Materials: Material Characterization (p.197)
- Functional Safety: Active Resilience (p.82)
- Hardware Security and Trust (p.87)
- Laser scanning for mapping large structures (p.107)
- Mechanical Properties and Degradation Mechanisms (p.125)
- Optical Metrology for Sustainable Production (p.161)
- Particle Methods in Engineering (p.140)
- Physics of Failure (p.100)
- Quantification of Resilience (p.170)
- Reliability Engineering (p.201)
- Structural Robustness: Resilient Designs (p.181)

Information Processing Technologies

- Artificial Intelligence Planning (IIF)
- Compiler Construction (p.40)
- Cyber-Physical Systems – Discrete Models (p.46)
- Cyber-Physical Systems – Hybrid Models (p.48)
- Cyber-Physical Systems – Program Verification (IMTEK)
- Embedded Control Laboratory (p.68)
- High-Performance Computing with Python (p.89)
- Introduction to Embedded Systems (p.58)
- Functional Safety: Active Resilience (p.82)
- Foundations of Artificial Intelligence (IIF)
- Machine learning (IIF)
- Machine Learning for Automated Algorithm Design (IIF)
- Micro-electronics (p.129)
- Microcontroller Techniques - Laboratory (IMTEK)
- Modelling and System Identification (p.131)
- MST Design Lab (p.135)
- Network Algorithms (IIF)
- Numerical Optimal Control in Science and Engineering (p.145)
- Numerical Optimal Control in Engineering – Project (p.147)
- Python for Energy System and Sustainability Analysis (p.168)
- Real-Time Operating Systems and Worst-Case Execution Times (IIF)
- Security and Privacy in the Information Society (p.178)
- Spectral Simulation Methods with Python (IMTEK)
- Statistical Pattern Recognition (IIF)
- Verification of Digital Circuits (p.195)
- Wind energy systems (p.199)
- Wireless Sensor Networks (p.54)

Interdisciplinary Profile

The following list shows the various courses that have been credited for the Interdisciplinary Profile in the past. The list is sorted by name of the institution within the University offering the course. If the module name is in German, the course is held in German language. If the courses are not offered by the Faculty of Engineering, you will have to take care of further information about the course yourself. Normally, you will find information about the course and its contact person in HISinOne or on the respective websites of the institutions offering the courses. **The different faculties and departments may have different registration requirements and procedures.** Often, if you want to attend a course outside of your own degree program, you cannot register directly. In this case, you may have to contact the respective professor. Please make sure that you will inform yourself **in good time** and, if necessary, get in touch with the professors responsible. In particular, seminars have only a limited number of participants and therefore have special registration requirements.
For courses offered by University College Freiburg (UCF), SSE students will register online through HISinOne (modules are called "00LE62MO-LAS-EXP1 Liberal Arts and Sciences Wahlmodul" – I , II, and III). Take into account that there are just limited spots available in UCF courses. UCF reserves the right to allocate seats.
Please note that just because the course is listed below does not automatically mean that you may get a seat. Furthermore, some courses that are listed here are not offered regularly and therefore cannot be re-booked. Nevertheless, the list gives an insight into which institutions may offer interesting courses for your Interdisciplinary Profile.

You are welcome to select further courses from the extensive range offered by the University of Freiburg. **However, before students register for new courses (new = not listed below), the course has to be checked regarding its suitability for the M.Sc. SSE program. This is done by the dean of academic affairs. Students therefore must send an e-mail with all necessary information about their course of choice to the program coordinator (study@inatech.uni-freiburg.de) at the latest two weeks before lectures start! Deadlines are strictly enforced! Registering first and/or participating in the course already and asking for "recognition" of the course later (basically after having "created facts") is considered inappropriate and will lead to non-recognition of the course. The necessary information includes at least: number, name and content outline of the course, ECTS credits, course-based assessment (PL), coursework (SL), internet link to further information if available, name of offering institution and/or contact person.**

The following list shows the various courses that have been credited for the Interdisciplinary Profile in the past.

Technische Fakultät / Faculty of Engeneering

- Complex Networks (p.42)
- Computational Modeling with Matlab (p.44)
- Energy Economics (p.74)
- Energy Economics and Energy Policy (until winter term 2018/19; not available anymore)
- Environmental Psychology for Engineers (p.79)
- Gender Studies in MINT (IIF)

- Innovation and Evolution of Technical Systems (p.94)
- Neuroscience for Engineers (p.143)
- Operations Research for Energy Systems (p.152)
- Project management for engineers (p.166)
- Scientific writing and presentation (p.81)
- The science of complex systems - fundamentals and applications (p.193)

Wirtschafts- und Verhaltenswissenschaftliche Fakultät / Faculty of Economics and Behavioral Sciences
Institut für Wirtschaftswissenschaften / Institute of Economics and Business

- Advanced Microeconomics I
- Basic Income and Social Justice
- Behavioral Economics
- Economics of Climate Change
- Entrepreneurship und Social Entrepreneurship
- Futures and Options
- Organizational Behavior and Leadership
- Verhaltenswissenschaftliche Grundlagen des Public und Non-Profit Management

Zentrum für Schlüsselqualifikationen / Center for Key Qualifications

- Basiskompetenzen Kommunikation und Gesprächsführung
- Der Businessplan: methodische Grundlagen für die unternehmerische Selbstständigkeit und zur Realisierung eigener Ideen
- Desktop Publishing – Grundlagen grafischer Gestaltung am Computer
- Entrepreneurship (lecture series)
- Grundlagen Rhetorik und Präsentation
- Intercultural Competence for international Students
- (Meine) Perspektiven nach dem Studium – Berufsfelder, Einstiegswege und Bewerbungstipps
- Methoden zur Entscheidungsfindung
- Ökonomie und Verantwortung für Morgen – Nachhaltige Wirtschafts- und Lebensstile angesichts des Klimawandels
- Print- & Online-Publishing – Grafische Gestaltung an PC und mobilen Geräten
- Professions in Sustainability – Skills for Planning Sustainable Development as Exemplified by Tourism, Sport, and Nature Conservation
- SAP & Co. – eine Einführung in die Funktionsweise von Software zur Abbildung von Unternehmensprozessen
- Von der klassischen zur gegenwärtigen Rhetorik – überzeugend Reden und Vortragen

University College Freiburg

- Behavioral Economics and the Individual Process of Decision Making
- Climate Change & Biodiversity
- Computational Modeling
- Economics of Climate Change
- Energy Policy
- Energy / Energy Technologies
- Environment, Risks, and Us
- Environmental Controversies
- Environmental Chemistry Seminar

- Environmental Psychology
- Geographic Information Systems (GIS) Seminar
- Geohazards
- Human Physiology
- Introduction to Earth and Environmental Sciences
- Political Theory
- Resources and Sustainability
- Robot Design – Theory, Practice, Philosophy
- The Earth in the Universe
- Urban Environmental Planning in Response to Climate Change

Philosophische Fakultät / Faculty of Philosophy

- Einführung in die allgemeine Ethik
- Verhandlungssimulation EU-UN

M.Sc. Geography

- Resilience thinking: examining theory and application in geography and urban planning
- Politische Geographien von Logistik und Infrastrukturen

Fakultät für Umwelt und Natürliche Ressourcen / Faculty of Environment and Natural Resources

- Klimawandelanpassung in Ländern des globalen Südens
- Klima und Wasser
- Ecosystem management

Institute of Physics

- Laser-based Spectroscopy and Analytical Method

Fakultät für Chemie und Pharmazie / Faculty of Chemistry and Pharmacy

- Sustainability ... in a chemical and energy context (summer 2019)

Other

- Intercultural Mentoring Program: https://www.mentoring.uni-freiburg.de/intercultural/mentors

List of all mandatory modules (alphabetical order)

Modul / *Module*
Energiespeicherung / Energy Storage

Nummer *Number*	11LE68MO-8010		
Modulverantwortlicher *Responsible person*	M. Vetter, D. Schossig, T. Smolinka	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Mandatory Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Basic understanding of Engineering Physics and Engineering Chemistry		

Empfohlenes Fachsemester *Recommended term of study*	1	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	3 lectures + 1 exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150 hours (56 hours full-time attendance course of study + 94 hours self-study)		

Lernziele / *Learning objectives*

- Understanding the necessity of energy storage (short-term, mid-term, seasonal) for stationary applications (electric, thermal and chemical) as well as their technical and economic requirements
- Basic knowledge of different energy storage technologies such as pumped-hydro, SuperCaps, batteries, and thermal storage systems as well as hydrogen and Power-to-Gas (PtG) solutions
- Knowledge in design of battery systems with a focus on lihtium-ion technologies
- Knowledge in design of thermal storage systems
- Knowledge in design of hydrogen storage and PtG systems

Inhalte Vorlesung / *Content of the lecture*

1. Introduction and motivation energy storage (electric, thermal, PtG): Large-scale integration of renewable energies and the role of energy storage; technical requirements of power grids; overview of energy storage options and applications; key parameter of energy storage systems; technical requirements of storage systems; economic analyses for storage systems

2. Basics of energy storage systems: Mechanical (pumped hydro, CAES, fly wheels); Electric (SuperCaps); Electrochemical (Lead-acid, NiCd, NiMh, Lithium-ion; Sodium-ion; NaS / NaNiCl); thermal storage systems; chemical storage and PtG systems
3. Design of battery systems (focus Lithium-ion): Test and characterization of cells; Battery module and system design (components, construction, cooling); Safety issues; Battery management; Thermal management; System integration (system options, power and communication interface); Peripheral components (inverter, energy management)
4. Design of thermal storage systems
Description of technologies: sensible heat storage, latent heat storage, thermochemical storage. Technical applications: long term storage, short term storage, from cold storage to high temperature storage. Component and system layout, best case examples, limits and future expectations
5. Design of hydrogen storage and PtG systems: different system layouts and main components of hydrogen and PtG storage systems, water electrolysis as core component for PtG systems, advantages and drawbacks for repowering in fuel cells and thermal engines, best case examples of PtG installations, intersectoral extention to further Power-to-X technologies

Inhalte Übung / *Content of the exercises*

The lecture will be accompanied by a weekly exercise to deepen the understanding of the lecture's content and to discuss further details.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Zu erbringende Studienleistung / *Coursework*

Written or oral examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Literatur / *Literature*

T. Letcher: Storing Energy
G. Pistoia: Lithium-Ion Batteries Advances and Applications
A. Jossen: Moderne Akkumulatoren richtig einsetzen
J.-C. Hadorn: Thermal energy storage for solar and low energy systems
P. Moseley and J. Garche: Electrochemical Energy Storage for Renewable Sources and Grid Balancing

Modul / *Module*

Grundlagen resilienter/stabiler Systeme / Fundamentals of Resilience

Nummer *Number*	11LE68MO-8020		
Modulverantwortlicher *Responsible person*	S. Hiermaier	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Mandatory Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Engineering Physics		

Empfohlenes Fachsemester *Recommended term of study*	1	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	4 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150 hours (56 hours Full-time attendance course of study + 94 hours Self-study)		

Lernziele / *Learning objectives*

An engineering design that provides safety and security, comfort for the customer, efficient use of energy and resources, lowest possible emissions and economical advantages is called sustainable. Ongoing research towards sustainable solutions in engineering design show that the ability of systems to recover from catastrophic, disruptive events is another essential component in the list of attributes a sustainable solution needs to contain. Urban infrastructure, future mobility and energy technologies are key elements of a living society. Disruptive processes as for example natural disasters, terroristic assassinations, technical failure or human error cause a dramatic drop in the performance of the system. Resilience of the system can be measured using the time integral of lost performance. The better a system has been designed to over such a disaster the shorter is the time to recover and the higher is its resilience.

Inhalte Vorlesung / *Content of the lecture*

The lecture provides a clear understanding of the term “resilience” in an engineering context, specifically as compared to stability, robustness, flexibility or failure safety. Students realize that failure of transport systems, infrastructure, support chains and of other technical systems is not necessarily a consequence of technical malfunction or bad design. Students find that in contrast the ability to control failure of systems and catastrophes can be achieved by networks of perspective interaction, prevention and adaption. Continuous

adaption of behavior of individuals and of the control of facilities will be understood as necessary steps towards increasing resilience.

- key concepts and ideas in resilience engineering
- collection of typical systems addressed concerning their resilience
- introduction to tools for quantitative risk analyses

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Zu erbringende Studienleistung / *Coursework*

Written or oral examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Literatur / *Literature*

- Thoma, Klaus/Scharte, Benjamin/Hiller, Daniel/Leismann, Tobias (2016): Resilience Engineering as Part of Security Research: Definitions, Concepts and Science Approaches. In: European Journal for Security Research, 1:1, 3-19.
- Häring, Ivo/Ebenhöch, Stefan/Stolz, Alexander (2016): Quantifying Resilience for Resilience Engineering of Socio Technical Systems. In: European Journal for Security Research, 1:1, 21-58.
- Häring, Ivo (2016): Risk Analysis and Management: Engineering Resilience. Singapore: Springer.
- Linkov Igor/Kröger, Wolfgang/Renn, Ortwin/Scharte, Benjamin et al. (2014): Risking Resilience: Changing the Resilience Paradigm, Commentary to Nature Climate Change, 4: 6, 407-409.

Modul / *Module*
Masterarbeit / Master‘s Thesis

Nummer *Number*	11LE68MO-8700-672		
Modulverantwortlicher *Responsible person*	Examiners of the Department of Sustainable Systems Engineering	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Mandatory module	**Moduldauer** *Module duration*	1 term
Lehrveranstaltungstyp *Type of course*	Written thesis	**Sprache** *Teaching language*	German or English
Zwingende Voraussetzungen *Mandatory requirements*	Admission for the thesis can be granted once at least 70 ECTS-credits have been acquired within the course program.		

Empfohlenes Fachsemester *Recommended term of study*	4	**ECTS-Punkte** *ECTS credits*	30
SWS *Semester week hours*		**Angebotsfrequenz:** *Regular cycle*	Each term
Arbeitsaufwand *Workload*	900 hours (900 hours self-study)		

Lernziele / *Learning objectives*
The student shows with his/her Master thesis the ability to solve a given problem from sustainable systems engineering in a given time frame using scientific methodology. Skills and competencies obtained in the course program have been verifiably applied in accordance to the state of the art. The student has proven his/her ability to apply methods and knowledge as well as research and development competencies in the project, the scientific documentation and the oral presentation.

Inhalte / *Content*
The Master’s thesis is an independent research project. Is consists of a written documentation and a final presentation with discussion. The student works on a given topic for a given timeframe and has to deliver a scientific documentation.

Zu erbringende Prüfungsleistung / *Course-based assessment*
The Module consists of a written documentation of the thesis and an oral presentation of the results of the thesis. The final module grade is calculated from the grade of the written thesis.

Benotung / *Grading*
The final module grade is calculated from the grade of the written thesis.

Modul / *Module*
Masterprojekt / Master‘s Project

Nummer *Number*	11LE68MO-7160		
Modulverantwortlicher *Responsible person*	Prof. Dr. Oliver Ambacher	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Mandatory module	**Moduldauer** *Module duration*	1 term
Lehrveranstaltungstyp *Type of course*	Individual project with colloquium	**Sprache** *Teaching language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	None		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte:** *ECTS credits*	5
SWS *Semester week hours*	3	**Angebotsfrequenz** *Regular cycle*	Each term
Arbeitsaufwand *Workload*	150 hours self-study.		

Lernziele / *Learning objectives*

Having successfully completed this module, students will be able to:

- define a proper research idea related to sustainable systems
- plan and design its implementation according to given circumstances,
- gather and process data and information scientifically,
- conduct the research including experimental work (if applicable), and
- present the results/outcomes (poster, presentation) as part of a scientific workshop

Inhalte Kolloquium / *Content of the colloquium*

Research topics will be made available by internal or external supervisors (e.g. from the University or Fraunhofer institutes). Alternatively, students can come up with their own research topics and a suggestion for a possible supervisor. The topic must have technical proximity to the SSE program, be of scientific nature, and be suitable for the necessary work load of 150 hours which needs to be confirmed by the responsible person of this module. A regular colloquium will be offered in winter term (recommended term of study = 3). A professional two-day workshop will be organized at the end of the winter semester during which all SSE students will present their results. All supervisors, SSE students, and

professors will be invited to this event. It is highly recommended that all SSE students conduct their master project in winter term. However, they are allowed to also conduct it in summer term. Students, who conduct their master project during the summer term, will present their results during the examinations phase.

Zu erbringende Studienleistung / *Coursework*

Poster and oral presentation as part of the “Master-Project-Workshop”. Templates for the poster will be made available on ILIAS or by email. The poster must be submitted via e-mail by the student to the responsible person of this module by a given deadline (will be announced by the beginning of the semester). The presentation will be held either at the above mentioned workshop (winter term) or at a given examinations date to be defined (summer term).
In both, winter and summer term, students must not forget to register for the master project exam (Studienleistung)!

Benotung / *Grading*

The grading of the master project will be related to the poster (weight 50%) and oral presentation (weight 50%) and will be defined by a group of advisors present in the workshop (winter term) or during the examination (summer term).

Literatur / *Literature*

Will be provided by the advisor of the master project and will be project specific.

Modul / *Module*
Materiallebenszyklen / Material Life Cycles

Nummer *Number*	11LE68MO-8030		
Modulverantwortlicher *Responsible person*	S. Hiermaier, S. Kilchert	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Mandatory Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Fundamental knowledge of Materials Science and Technology		

Empfohlenes Fachsemester *Recommended term of study*	1	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 lecture + 2 exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150 hours (56 hours Full-time attendance course of study + 94 hours Self-study)		

Lernziele / *Learning objectives*
The aim of the lecture is to be introduced to a framework within which a student can form critical, independent assessments of Sustainable Developments. With a focus on the role of materials it recognizes the complexity inherent in discussions of sustainability and shows how to deal with it in a systematic way.

Inhalte Vorlesung / *Content of the lecture*
For that purpose the students are provided with procedures and tools, which allow them to analyze the financial, natural, human and social factors contributing to sustainable development. Within that context, the lecture addresses questions such as “How do we achieve sustainable development? How do we measure progress in achieving it? What does it mean in engineering practice? How do materials fit in?” The students will find that there is no completely “right“ answer to questions of sustainable development- instead, there is a thoughtful, well-researched response that recognizes the conflicting priorities of the environmental, the economic, the legal and the social aspects of a technological change.

Inhalte Übung / *Content of the exercises*
Students will learn to assess sustainability aspects of materials & processes via hands-on sessions using specialized databases.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Zu erbringende Studienleistung / *Coursework*
Written or oral examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Literatur / *Literature*
Michael F. Ashby, "Materials and Sustainable Development", Elsevier, 2016. Michael F. Ashby, "Materials and Environment", Elsevier, 2013.

Modul / *Module*
Netzintegration und Regelung / Control and Integration of Grids

Nummer *Number*	11LE68MO-8090		
Modulverantwortlicher *Responsible person*	Prof. Dr. Anke Weidlich	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Mandatory Module	**Moduldauer** *Module duration*	1 Term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen: *Recommended preconditions*	Fundamentals of Electrical Engineering or Engineering Physics		

Empfohlenes Fachsemester *Recommended term of study*	1	**ECTS-Punkte:** *ECTS credits*	5
SWS *Semester week hours*	3 Lecture + 1 exercise	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150 hours (42 hours full-time attendance course of study + 108 hours self-study)		

Lernziele / *Learning objectives*

The aim of this module is to get an understanding of the power and energy definition in energy systems and distribution grids. The module will cover the traditional electrical energy system structures as well as the renewable energy systems. Focus will be on the analysis of electrical grids, used for optimized integration of distributed energy resources.

Inhalte Vorlesung / *Content of the lecture*

- Energy system overview – generation, transmission, distribution, consumption
- Energy transport; power and energy definition
- Power generation analysis;
- Transition of the energy systems; renewable energy grid integration
- Power plants, storage, inverters
- Grid theory; DC, AC circuits; system theory
- System components: lines; transformers; generators;
- Grid calculation; reactive and active power flow
- Grid codes, grid regulation
- Operation and control of electricity grids; primary, secondary and tertiary control; voltage control
- Economic dispatch problem

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written supervised examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Zu erbringende Studienleistung / *Coursework*
Written supervised examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Literatur / *Literature*
Power Generation Technologies; Paul Breeze ISBN 978-0-08-098330-1 Electric Power Generation Transmission and Disitribution; Leonard L. Grigsby; ISBN 978-1-4398-5628-4

Modul / *Module*
Numerische Methoden der Materialwissenschaften / Computational Materials Engineering

Nummer *Number*	11LE68MO-8050		
Modulverantwortlicher *Responsible person*	M. Moseler	**Einrichtung** *Organisational unit*	Physics/ Faculty of Engineering
Modultyp *Module Type*	Mandatory Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Basic knowledge in classical mechanics, analysis and vector calculus.		

Empfohlenes Fachsemester *Recommended term of study*	1	**ECTS-Punkte:** *ECTS credits*	5
SWS *Semester week hours*	2 lectures + 2 exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150 hours (64 hours full-time attendance course of study + 86 hours self-study)		

Lernziele / *Learning objectives*
Students will become familiar with the various methods of computational materials science: density functional theory, tight-binding, semi-empirical interatomic potentials, coarse grained models, continuum models. Students will be able to set up density functional and molecular dynamics simulations to understand and design sustainable materials.

Inhalte Vorlesung / *Content of the lecture*
An introduction into basic concepts of computational materials science will be given. The computational tools for different time and length scales will be introduced and it will be discussed how these tools can be combined in order to solve multiscale materials problems.The lecture will start with a brief introduction to density functional theory and tight binding. With both methods the short term dynamics of small units of materials can be studied. For the simulation of larger systems and longer time scales, classical interatomic potentials will be introduced allowing for the description of the different types of bonding in materials. The basic methodology of extended molecular dynamics simulations will be introduced. Finally, concepts for coarse grained methods to study the mesoscale and macroscale dynamics in solids and liquids will be discussed.

Inhalte Übung / *Content of the exercises*

The lecture is accompanied by a python-based hands-on programming course. For simple materials systems a working knowledge in molecular dynamics will be taught.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written supervised examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Zu erbringende Studienleistung / *Coursework*

Written supervised examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Literatur / *Literature*

- Daan Frenkel, Berend J. Smit, Understanding Molecular Simulation, Elsevier, ISBN: 978-0-12-267351-1
- Michael Griebel, Stephan Knapek, Gerhard Zumbusch, Numerical Simulation in Molecular Dynamics, Springer, ISBN 978-3-540-68095-6
- Tamar Schlick, Molecular Modelling and Simulation, An interdisciplinary guide, Springer. ISBN 978-1-4419-6351-2
- C. Fiolhais, F. Nogueira, M. Marques, A Primer in Density Functional Theory. Springer. ISBN: 3540030832
- Lecture script
  M.Moseler "A brief introduction into Computational Materials Science"

Modul / *Module*
Solare Energie / Solar Energy

Nummer *Number*	11LE68MO-8060		
Modulverantwortlicher *Responsible person*	S. Glunz, K. Kramer, P. Schossig, A. Heimsath	**Einrichtung** *Organisational unit*	Faculty of Engineering / INATECH
Modultyp *Module type*	Mandatory Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Basic understanding of physics		

Empfohlenes Fachsemester *Recommended term of study*	1	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	4 lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150 hours (42 hours full-time attendance course of study + 108 hours hours self-study)		

Lernziele / *Learning objectives*

Students will be able to understand the fundamentals and different technology variants of solar energy conversion such as photovoltaics and solar thermal. They will know the relevant physical background, technical characteristics, materials and designs used. The lecture will cover the component, product and system level. Furthermore students will understand trends of further development as well as limitations and possibilities in application of solar energy.

Inhalte Vorlesung / *Content of the lecture*

- Solar Energy - Theoretical and Technical Energy Potential (black body radiation, Carnot cycle, maximum efficiencies, …)
- Solar Energy Technologies - Tapping the sun's energy (overview of conversion technologies, system boundaries, seasonal fluctuation, ...)
- Photovoltaics - Physics of Solar Cells (introduction to semiconductors, Fermi levels, IV curves, conversion efficiency, quantum efficiency …)
- Photovoltaics - Technology Review (short introduction to the structure and technology of crystalline silicon solar cells)
- Solar Thermal - Physics of Solar Collectors (basics of thermo dynamics, fluid dynamics, absorption, emission, power output and other performance criteria)

- Solar Thermal - Technology Review (from low temperature applications up to power plants - examples)
- Heat pumps - Thermodynamics, electrical and thermal driven heat pumps and chillers, main components (compressor, evaporator, condensor etc.), system configurations (layout, sources, storages, control strategies etc)
- Heat pumps: field tests and best case examples - Heat pumps and smart grid interaction, Heat pumps and PV, Heat pumps + solar thermal, storage integration)

The lecture will be accompanied by a weekly exercise to deepen the understanding of the lecture's content and to discuss further details.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written supervised examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Zu erbringende Studienleistung / *Coursework*

Written supervised examination (the Prüfungsleistung is the same as the Studienleistung; students do either Studienleistung or Prüfungsleistung, not both; see examination regulations)

Literatur / *Literature FORMAT bei allen Modulen konsistent*

- Duffie-Beckman: Solar Engineering of Thermal Processes,
- V. Quaschning: Understanding Renewable Energy,
- Peuser FA, Remmers K, et.al.:Solar thermal systems
- P. Würfel, Physik der Solarzelle, Spektrum - Akademischer Verlag 2000
- Goetzberger, B. Voß und J. Knobloch, Sonnenenergie: Photovoltaik, Teubner 1997
- M.A. Green, Solar Cells, University of New South Wales 1982
- K. Mertens, Photovoltaik, Hanser 2011
- J. Nelson, The physics of solar cells, Imperial College Press 2008

List of elective modules (alphabetical order)

Modul / *Module*
Bauelemente und Schaltungen der Leistungselektronik/ Power Electronic Circuits and Devices

Nummer *Number*	11LE68MO-9010		
Modulverantwortlicher *Responsible person*	O. Ambacher, R. Quay, B. Burger	**Einrichtung** *Organisational unit*	INATECH & IMTEK
Modultyp *Module type*	Mandatory elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercise	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Basic knowledge of electric and electronic circuits		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 lecture + 2 exercise	**Angebotsfrequenz** *Regular cycle*	Each summer term
Arbeitsaufwand *Workload*	150h (52h full-time attendance course of study + 98h self-study)		

Lernziele / *Learning objectives*

Students will be enabled to understand materials, functioning and design of up to date power devices and circuits suitable for energy efficient power electronic systems. The lecture comprises three aspects: fundamental material and device concepts, power conversion-circuitry and power conversion systems. This includes high voltage AC-DC converter, solar energy photovoltaic converters and convertres for engines or windcraft systems. The basic concepts of power conversion, of passive and active semiconductor devices, high-voltage operation, converter- and control concepts, device protection and aspects of system and power network theory are provided.
The students will be competent to analyze, understand the fabrication, design of passive and active power devices such as MOSFETs, Insulated Gate Bipolar IGBTs, Junction FETs (JFET), diodes, and thyristors. Students will be able to design and analyze feedback control systems based on state space control technologies and apply them to power devices.

Die Studenten werden in die Lage versetzt, Materialien, Entwurf und Funktionen von modernen Leistungsbauelementen und Schaltkreisen zu verstehen, die für energieeffiziente leistungselektronische Systeme geeignet sind. Die Vorlesung umfasst drei Aspekte: grundlegende Materialkonzepte, Bauelementkonzepte und Spannungswandler sowie Stromrichter-Systeme. Dazu gehören Hochspannungs-AC-DC-Wandler, photovoltaische

Photovoltaik-Konverter und Konverter für Motoren oder Windkraftanlagen. Die grundlegenden Konzepte der Leistungswandlung, der passiven und aktiven Halbleiterbauelemente, des Hochspannungsbetriebs, der Umrichter- und Steuerungskonzepte, des Geräteschutzes sowie der System- und Netzwerktheorie werden vorgestellt. Die Studenten werden ausgebildet, um die Herstellung von passiven und aktiven Leistungsbauelementen wie MOSFETs, Bipolar-IGBTs, Junction-FETs (JFET), Dioden und Thyristoren zu analysieren und zu verstehen. Die Studierenden werden in der Lage sein, Rückkopplungs-Steuerungssysteme basierend modernen Architekturen zu entwerfen und zu analysieren und sie auf leistungselektronische Systeme anzuwenden.

Inhalte Vorlesung / *Content of the lecture*

The lecture deals with the materials, topologies and concepts of power devices and circuits. It comprises three parts: fundamental material and device concepts, power conversion-concepts and actual power conversion systems. At the interface of modern electronics, circuit design, and control theory, advanced analysis, fabrication, and characterization techniques are introduced in order to bridge the gap from modern power conversion to the understanding of systems and network systems with all aspects of power conversion. The methodologies of power-analysis, design of circuits, complex power flow, processing of devices, their modelling, their characterization, and control are introduced along with the demonstration of their relevance to real power-components and -systems. Circuits and system concepts for power conversion, such as half and full bridges, current controls, aspects high voltage operation, and design for robustness are presented, and several examples are discussed in detail. Typical applications include DC-DC conversion for server systems, photovoltaic power conversion, application to microscopic power converters, and high-voltage windcraft systems.

Die Vorlesung beschäftigt sich mit den Materialien, Topologien und Konzepten von Leistungsbauelementen und Schaltungen. Sie besteht befasst sich mit drei Themen: grundlegenden Material- und Bauelementkonzepten, Energiekonversionskonzepten und Energiewandlungssystemen. An der Schnittstelle von moderner Elektronik, Schaltungsentwurf und Steuerungstheorie werden moderne Analyse-, Herstellungs- und Charakterisierungstechniken eingeführt, um das Wissen von ausgehend von modernen leistungselektronischen Bauelementen bis zum Verständnis von Systemen zur Energieumwandlung bereitzustellen. Die Methoden der Leistungsanalyse, der Entwurf von Schaltungen, der Prozessierung von Schaltungen, ihrer Modellierung, ihrer Charakterisierung und Regelung werden vorgestellt und ihre Relevanz für reale Leistungskomponenten und -systeme demonstriert. Schaltkreise und Systemkonzepte für die Energieumwandlung, wie Halb- und Vollbrücken, Stromsteuerungen, Hochspannungsbetrieb und Designs mit hoher Robustheit werden vorgestellt. Typische Anwendungen sind die DC-DC-Wandlung für Serversysteme, die photovoltaische Leistungsumwandlung, die Anwendung in mikroskopischen Stromrichtern und Windkraftanlagen.

Inhalte Übung / *Content of the exercises*

In the exercises, the contents of the lecture will be illustrated and deepened by means of examples. The students learn in their home studies on the basis of exercise sheets, e.g. to calculate the electrical properties of power electronic devices and circuits, as well as to estimate the lifetime, ruggedness, and energy efficiency of power electronic systems. During the exercises the solutions of the tasks and problems are presented by tutors and explained in detail.

In den Übungen werden die Inhalte der Vorlesung anhand von Beispielen veranschaulicht und vertieft. Die Studierenden erlernen im Eigenstudium anhand von Aufgabenblättern z.B. die elektrischen Eigenschaften von leistungselektronischen Bauelementen und Schaltungen zu berechnen sowie die Lebensdauer, Robustheit und Energieeffizienz von leistungselektronischen Systemen abzuschätzen. Die Lösungen der Aufgabenblätter werden in der Übung durch Tutoren vorgestellt und detailliert erklärt.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written supervised exam

Zu erbringende Studienleistung / *Coursework*
None

Literatur / *Literature*
• Joachim Specovices „Grundkurs Leistungselektronik“ Vieweg + Teubner (2009) ISBN 9783834805577 • Manfred Michel „Leistungselektronik“ Springer (2011) ISBN 9783642159831 • C. Kamalakannan et al. „Power Electronics and Renewable Energy Systems“ Springer (2014) ISBN 8132221184

Modul / *Module*
Bioinspirierte Funktionsmaterialien / Bioinspired functional materials

Nummer *Number*	11LE50MO-5125		
Modulverantwortlicher *Responsible person*	Dr. Osorio-Madroza	**Einrichtung** *Organisational unit*	IMTEK; Chair for Sensors
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	German or English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Only in the summer term
Arbeitsaufwand *Workload*	90 hours (28 hours full-time attendance course of study + 62 hours self-study)		

Lernziele / *Learning objectives*

In this module the students will get fundamental knowledge on the structure and functionality of biological materials as to apply their design principle in the development of bioinspired biomaterials. At the end of the module, the student should be able to describe the interrelation between microstructure and properties in biological materials; apply advance methods for the characterization of microstructure and properties of biological and artificially developed bioinspired materials and explain the method theoretical principle; and describe the physico-chemistry of the processing of different bioinspired materials studied in the course.

Inhalte Vorlesung / *Content of the lecture*

- Organic-based biological materials. Hierarchical structure and functionality
- Mineralized biological materials. Hierarchical structure and functionality
- Advanced methods to characterize the microstructure and properties of biological and bioinspired materials (Materials physical-chemistry and materials physics: mechanical testings; scattering techniques SAXS and WAXS for microstructure characterization; spectroscopic techniques for chemical structure characterization). Establishment of

structure-properties relationship in biomaterials
- Examples of preparation methods of bioinspired materials. Processing physical-chemistry and optimization
- Interrelation between processing, structure and properties in bioinspired materials
- - Examples of bioinspired materials for technological and biomedical applications

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Literatur / *Literature*

Modul / *Module*
Bionische Sensoren / Bionic Sensors

Nummer *Number*	11LE50MO-5701		
Modulverantwortlicher *Responsible person*	Prof. G. Urban, Dr. Can Dincer	**Einrichtung** *Organisational unit*	IMTEK; Sensoren
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture (the associated laboratory, see further below, is not obligatory and limited in places)	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	None		
Zwingende Voraussetzungen *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	1 Lecture	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90h (14 hours full-time attendance course of study + 76 hours self-study)		

Lernziele / *Learning objectives*

The aim of this module is a basic understanding of electrical, electrochemical and optical chemo- and biosensor principles as well as the basic knowledge of biological sensors. Principles of bioinspired system and the background of bionic learning from nature to realize microtechnological systems will be discussed.
Basics of electrical charge transfer and information processes in biological systems will be presented.

Inhalte Vorlesung / *Content of the lecture*

The lecture bionic sensors deal with learning from nature to realize technical chemo- and biosensors.

Topics are:
- Biological sensors/receptors
- Charge transfer and information processes in biology
- Chemosensor, introduction
- Basics of electrochemistry
- Electrochemical potentiometric sensors

- Electrochemical amperometric sensors
- Gas sensors
- Biosensors

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Zu erbringende Studienleistung / *Coursework*

Literatur / *Literature*

Modul / *Module*
Bionische Sensoren - Praktikum / Bionic Sensors - Laboratory

Nummer *Number*	11LE50MO-5702		
Modulverantwortlicher *Responsible person*	Prof. G. Urban	**Einrichtung** *Organisational unit*	IMTEK; Sensoren
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen: *Connected events*	Lab	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Knowledge of the contents of the modules „sensors", "bionic sensors" and "BioMEMS".		

Empfohlenes Fachsemester: *Recommended term of study*	3	**ECTS-Punkte:** *ECTS credits*	3
SWS: *Semester week hours*	3 Lab	**Angebotsfrequenz:** *Regular cycle*	Winter term; always at the end of winter term, during the examination phase; limited number of participants.
Arbeitsaufwand: *Workload*	90h (48 hours full-time attendance course of study + 42 hours self-study)		

Lernziele / *Learning objectives*
Students should gain hands on experience with several types of sensors the theory of which has been presented in the lectures "Sensors and Actuators" as well as "Sensorik und Aktorik", and explained deeper in "Bionic Sensors" and "BioMEMS".

Inhalte Praktikum / *Content of the lab*
Five experiments will be offered with selected types of sensors described in the lectures mentioned above. Students will work with the sensors, calibrate them, build up experiments and perform detection and measurements with the sensors under supervision of tutors.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Graded protocols: Each student will have to write at least one report about one of the experiments she/he participated in; during each experiment a written test and continuous discussions will take place; practical skills of the students in accordance with the basic theory will be observed and graded.

Zu erbringende Studienleistung / *Coursework*

Literatur / *Literature*

Modul / *Module*
Compilerbau / Compiler Construction

Nummer *Number*	11LE13MO-1208		
Modulverantwortlicher *Responsible person*	Prof. Dr. Peter Thiemann	**Einrichtung** *Organisational unit*	IIF P Programmiersprache
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	lecture + exercise	**Sprache** *Language*	English or German
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	3 lecture + 1 exercise	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	180 hours (56 hours full-time attendance course of study + 124 hours self-study)		

Lernziele / *Learning objectives*

Die Studierenden sollen grundlegende Techniken und Werkzeuge des Compilerbaus kennen und anwenden können. Sie sollen in der Lage sein, Spezifikationen für die syntaktische und semantische Analyse zu lesen und selbst zu erstellen. Sie sollen alle Stufen eines einfachen Compilers kennen und in der Lage sein sie zu entwickeln und zu einem funktionierenden Compiler zusammenzusetzen. Sie sollen abstrakte Zwischenrepräsentationen und das Konzept des Staging von verschiedenen Verarbeitungsphasen kennen und anwenden lernen.

Students get to know and apply fundamental techniques and tools of compiler construction. They will be able to understand and develop specifications for syntactic and semantic analysis of a programming language. The will be able to name, explain and develop all stages of a simple compiler and put them together to build a working compiler. They get to know and apply the concepts of abstract intermediate representations as well as staging of different processing phases.

Inhalte Vorlesung / *Content of the lecture*

- Architektur eines Compilers
- Syntaktische und semantische Analyse
- Zwischensprachen und Transformation
- Instruktionsauswahl

- Registerallokation
- Analyse und Optimierung
- Garbage Collection
- Typen und Typinferenz

Inhalte Übung / *Content of the exercises*

Im Rahmen der Übung wird exemplarisch ein Compiler für eine kleine Programmiersprache entwickelt. Dabei kommen die Techniken und Inhalte der Vorlesung zum Einsatz.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination

Zu erbringende Studienleistung / *Coursework*

Literatur / *Literature*

- Andrew Appel with Jens Palsberg, Modern Compiler Implementation in Java,
- 2nd edition. Cambridge University Press (2002)
- Alfred V. Aho, Monica S. Lam, Ravi Sethi, and Jeffrey D. Ullman. Compilers,
- Principles, Techniques, and Tools (2nd Edition). Prentice Hall, 2006.
- Reinhard Wilhelm and Dieter Maurer. Übersetzerbau -- Theorie, Konstruktion,
- Generierung -- 2. Auflage. Lehrbuch. Springer-Verlag, Berlin, Heidelberg, 1996

Modul / *Module*
Complex Networks

Nummer *Number*	11LE68MO-5559		
Modulverantwortlicher *Responsible person*	Dr. Mirko Schäfer	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture with integrated exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Basic knowledge of matrix and probability theory. Basic knowledge of Python recommended.		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4 h lectures and integrated exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	180 (in class + preparation of classes)		

Lernziele / *Learning objectives*

After the completion of the course the student is expected to be able to

- describe how complex systems can be represented as networks
- calculate various measures for a given network
- compare the structure of different real world networks
- describe and explain network models covered in the course
- implement and analyse network models in the programming language Python, import data, plot results, visualise networks
- communicate and discuss the methods and results presented in current research papers from the field of complex networks

Inhalte Vorlesung / *Content of the lecture*

- the language of graph theory
- random graphs, small world and scale-free networks
- centrality measures

- economic and financial networks
- network components and the configuration model
- transport, contagion and diffusion processes on networks
- network synchronization
- network aspects of the electricity system
- large-scale renewable energy networks
- multiscale infrastructure networks

Zu erbringende Prüfungsleistung / *Course-based assessment*
None (because interdisciplinary profile)

Zu erbringende Studienleistung / *Coursework*
Written supervised exam

Literatur / *Literature*
• A.L. Barabási, *Network Science*, available at networksciencebook.com • Further literature will be announced in class

Modul / *Module*
Computational Modeling with Matlab

Nummer *Number*	11LE68MO-5557		
Modulverantwortlicher *Responsible person*	Dr. Reto Schölly	**Einrichtung** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Practical exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	No technichal requirements. Students who are attending or have attended Python for Energy System and Sustainability Analysis course can NOT take the Matlab course and vice versa.		
Empfohlene Voraussetzungen *Recommended preconditions*	An open mind and a determination to learn computational modeling and programming are absolute requirements. Clinging to pre-learned ideologies is not recommended.		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4 practical exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	180h		

Lernziele / *Learning objectives*
After successfully completing the course, students will have the ability to create, simulate and analyse computational models with Matlab.

Inhalte Vorlesung / *Content of the lecture*
This course introduces students to the basics of computational modeling with MATLAB. This software is a programming langu-age designed specifically for the creation, simulation and ana-lysis of mathematical models, including algebraic functions and differential equations. MATLAB can be described as the standard environment for engineering computing, and is capable of supporting all mathematical systems that can be computed numerically. There is a vast number of modules from various engineering fields available, including computer vision, finite element methods and others. Since other SSE courses focus on advanced models and simu-lations, course will only address the fundamentals of mathe-matical modeling with MATLAB. Its primary task is to teach students how to think as a programmer, how to turn a model into a functioning computer programme, and to solve basic problems from various fields. It is not designed to

address SSE-specific tasks, however, diligent students will be able to apply the knowledge gained to their academic interests.

Topics are:

- MATLAB fundamentals,
- Simulink fundamentals,
- digital image processing,
- economic models,
- differential equations with Simulink,
- artificial life models,
- population models,
- predator-prey systems.

During the course, students will get the opportunity to pick their own topic for the Final Project. Additionally, students will be given a list of project suggestions, out of which they can choose a topic, if they cannot find one on their own. It is highly recommended that the students choose a topic that interests them, be it on an academic or a personal level. Students are required to present the finished Final Project during the last few sessions (the dates for these will be announced at the beginning of the course). A presentation should take around 20 minutes, and working in groups of up to three is allowed.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Keine / None.
Nur Studienleistung / Only Course Work

Zu erbringende Studienleistung / *Coursework*

A total of 50 % score or more has to be achieved in order to pass the Studienleistung.
The Studienleistung consists of:

1. solving the tasks in the exercise sheets and uploading the results in time,
2. completing a Final Project and presenting it.
3. Attendance is obligatory.

Students must complete all exercise sheets and upload them to ILIAS as ZIP-compatible archives.
The course is an interactive guided exercise and, thus, students need to be present during at least 80 % of this time, in compliance to academic rules.
A Final Project must be completed and presented during a ~20 minutes presentation. Working in groups up to three is permitted.

Literatur / *Literature*

Students must have a laptop available throughout the course.

Modul / *Module*

Cyber-Physikalische Systeme – Diskrete Modelle / Cyber-Physical Systems – Discrete Models

Nummer *Number*	11LE13MO-2070		
Modulverantwortlicher *Responsible person*	Prof. Dr. B. Becker, Prof. Dr. A. Podelski, Prof. Dr. P. Thiemann, Prof. Dr. C. Scholl,	**Einrichtung** *Organisational unit*	Chair Rechnerarchitektur, Chair Softwaretechnik, Chair Programmiersprachen, Chair Betriebssysteme
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 Term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Knowledge in Rechnerarchitektur / Computer Architecture and Softwaretechnik / Software Engineering		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Term week hours*	3 Lecture + 1 Exercises	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	180 hours (64 full-time attendance course of study + 116 self-study)		

Lernziele / *Learning objectives*

Students understand how cyber-physical systems, in the wide range of their heterogeneous aspects (large-scale systems, system of systems, embedded systems, concurrent systems, hardware systems, software systems) can be modeled using the basic notion of transition systems. They know relevant formalisms for modeling correctness properties of cyber-physical systems, and they understand how the models can be analyzed using algorithmic methods in order to prove correctness or find errors.

Inhalte Vorlesung / *Content of the lecture*

The course provides an introduction to discrete models of cyberphysical systems, their analysis and verification:

- The students learn how to model cyber-physical systems as transition systems. Here, the main focus lies on software and hardware aspects of cyber-physical systems and on methods for modeling parallelism and communication.
- Moreover, the students learn how to express properties about such systems. The course covers different mechanisms to specify temporal properties including linear time properties and branching time properties such as LTL, CTL, and CTL* properties.
- Finally, the course demonstrates how to develop algorithms for checking whether

these properties hold. After presenting algorithms for explicit state systems we introduce symbolic BDDbased algorithms which are able to tackle the well-known “state explosion problem”. In addition, the course covers basic “Bounded Model Checking” (BMC) techniques which restrict the analysis to computation paths up to a certain length and reduce the verification problem to a Boolean Satisfiability problem.
- All necessary foundations for these algorithms such as fixed point theory, data structures like Binary Decision Diagrams (BDDs), and Satisfiability (SAT) solvers are introduced in the course as well.

Zu erbringende Prüfungsleistung / *Course-based assessment*
written or oral examination

Literatur / *Literature*
- Christel Baier, Joost-Pieter Katoen, Principles of Model Checking, MIT, 2008, ISBN 9780262026499 - B. Berard, M. Bidoit, A. Finkel, F. Laroussinie, Systems and Software Verification, Springer, 2001, ISBN 3642074782 - E. Clarke, O. Grumberg, D. Peled, "Model Checking”, MIT Press 1999 - Kropf, Thomas, "Introduction to Formal Hardware Verification", Springer, 1999, ISBN 3-540-65445-3

Modul / *Module*

Cyber-Physikalische Systeme – Hybrid-Modelle / Cyber-Physical Systems – Hybrid Models

Nummer *Number*	11LE13MO-1207		
Modulverantwortlicher *Responsible person*	Prof. Dr. B. Becker, Prof. Dr. A. Podelski, Prof. Dr. P. Thiemann, Prof. Dr. C. Scholl,	**Einrichtung** *Organisational unit*	Chair Rechnerarchitektur, Chair Softwaretechnik, Chair Programmiersprachen, Chair Betriebssysteme
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 Term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Knowledge in Rechnerarchitektur / Computer Architecture and Softwaretechnik / Software Engineering		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Term week hours*	3 Lecture + 1 Exercises	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	180 hours (56 full-time attendance course of study + 124 self-study)		

Lernziele / *Learning objectives*

Students understand how cyber-physical systems handling continuous data (e.g. receiving sensor values and controlling actuators) can be modeled based on transition systems. They know relevant formalisms for modeling systems with continuous parameters including time and probabilities, and they understand how the models can be analyzed using algorithmic methods in order to prove correctness or find errors.

Inhalte Vorlesung / *Content of the lecture*

The course provides an introduction to the modeling and analysis of hybrid systems, i.e. systems with discrete-continuous behavior, from the viewpoint of computer science.

- Hybrid automata are introduced as a syntactic model for hybrid systems. Corresponding labeled transition systems are used to define their semantics.
- Timed automata, as an important subclass of hybrid automata that extend discrete systems with a notion of time are considered. The branching time temporal logic TCTL is introduced to specify properties of timed automata and corresponding model checking algorithms are developed.
- As a further important subclass – more general than timed automata – we define linear hybrid automata. We show that the reachability problem for linear hybrid automata is in general andecidable, whereas boanded reachability, i.e., reachability

within a fixed number of steps, is still decidable and can be efficiently computed. We also consider boanded reachability for general hybrid automata and discuss corresponding solution approaches.
- Finally, the course provides basic knowledge on stochastic systems and corresponding model checking algorithms. To do so, we introduce discrete-time Markov chains (DTMMs) and probabilistic computation tree logic (PCTL).

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Literatur / *Literature*
Christel Baier, Joost-Pieter Katoen, Principles of Model Checking, MIT, 2008, ISBN 9780262026499

Modul / *Module*

Design und Monitoring großer Infrastrukturen / Design and Monitoring of Large Infrastructures

Nummer *Number*	11LE68MO-9020		
Modulverantwortlicher *Responsible person*	Prof. Dr. A. Reiterer, Dr. A. Stolz	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 lectures + 2 exercises	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	150 hours (56 hours Full-time attendance course of study + 94 hours Self-study)		

Lernziele / *Learning objectives*

The growing world population, the ongoing urbanization, the ever-increasing size, height and complexity of large scale built infrastructure lead to higher risks with respect to natural and manmade threats. Therefore smart designs and monitoring of large infrastructures are required.

Within this context the lecture provides insights in the basic requirements for a safe, secure and resilient design of construction and monitoring of those large urban infrastructures.

In detail students will learn about
- A set of fundamentals and tools to enable architects, structural engineers and building installation engineers assess the safety, security and resilience of designs and to optimize the integral design
- An overview about measurement techniques for monitoring such structures
- A deep view on the corresponding sensor and measurement concepts (focusing on optical systems)
- Using real time data streams for monitoring the resilience of infrastructure
- Smart and reinforced building elements, to measure the actual building condition combined with an increased bearing capacity and resistance

Inhalte Vorlesung / *Content of the lecture*
• Key concepts and ideas to design and monitor large urban infrastructures with respect to safety, security and resilience • Design concepts for sensor application and structural health monitoring • Data analysis methods for interoperating and visualizing measurements • Software aided assessment of infrastructures

Inhalte Übung / *Content of the exercises*
• Key concepts and ideas to design and monitor a large urban infrastructure safe, secure and resilient • Design concepts for sensor application and structural health monitoring • Data analysis methods for interoperating and visualizing measurements • Software aided assessment of infrastructures

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written examination and presentation

Literatur / *Literature*
• Literature will be provided at the beginning of the lecture

Modul / *Module*

Disposable sensors

Nummer *Number*			
Modulverantwortlicher *Responsible person*	Dr. Can Dincer (Lecturer) Prof. Dr. Gerald Urban	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture (additional lab available, see below)	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90h		

Lernziele / *Learning objectives*

- You understand the basics of different signal detection and amplification strategies.
- You know the materials and the fabrication techniques used for disposable sensors.
- You learn various biorecognition elements and their working mechanisms.
- You overview the recent advances in disposable sensors from different application fields.
- You can apply these knowlodge to develop new bioanalytical devices in future.

Inhalte Vorlesung / *Content of the lecture*

Disposable sensors are low-cost, single-use and easy-to-handle sensing devices. In recent years, they have become increasingly important for various applications. These include from environmental, forensic, pharmaceutical, agricultural, and food monitoring to wearables and clinical diagnostics, especially the point-of-care testing. This lecture deals with the materials, methods and applications of disposable sensors.

1. Introduction
2. Materials for disposable sensors
3. Biorecognition elements
4. Signal detection techniques
5. Signal amplification strategies

6. Lab-on-a-chip: integration into microfluidic systems
7. Application fields
   a. Diagnostics
   b. Food analysis
   c. Environmental monitoring
8. Future perspectives
9. Summary

Inhalte Übung / *Content of the exercises*
See additional lab course "Pape it lab: make (bio)analytical devices out of paper!"

Zu erbringende Prüfungsleistung / *Course-based assessment*
written or oral examination

Zu erbringende Studienleistung / *Coursework*
None

Literatur / *Literature*

Modul / *Module*
Drahtlose Sensornetze / Wireless Sensor Networks

Nummer *Number*	11LE13MO-1323		
Modulverantwortlicher *Responsible person*	Prof. Dr. C. Schindelhauer	**Einrichtung** *Organisational unit*	IMTEK, LS Rechnernetze und Telematik
Modultyp *Module type*	Wahlmodul	**Moduldauer** *Module duration*	1 Semester
Zugehörige Lehrveranstaltungen *Connected events*	Vorlesung und Übung	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	3 lecture + 1 exercise	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	180 hours (56 hours full-time attendance course of study + 124 hours self-study)		

Lernziele / *Learning objectives*

Die Studierenden kennen die konkreten Einsatzmöglichkeiten und Anforderungen drahtloser Sensornetze und können Standardmethoden in den einzelnen Schichten anwenden.

Inhalte Vorlesung / *Content of the lecture*

Abgrenzung von drahtlosen Sensornetzen zu mobilen Ad-Hoc-Netzwerken und zellulären Netzwerken, Hardware-Architektur, Software-Aufbau in WSN, die physikalische Schicht, Medium-Zugriff 802.15.4, Sensor-Mac, Routing, Datenzentralität, Informationsaggregation, Energie-Effizienz, Energy Harvesting, Resilienz in drahtlosen Sensor-Netzen, Lokalisierung

Inhalte Übung / *Content of the exercises*

Modulation, Fourier-Transformation, Routing, Lokalisierung, Medium-Zugriff, Synchronisierung, Netzwerk-Lebenszeit
aktive Teilnahme im Übungsbetrieb

Zu erbringende Prüfungsleistung / *Course-based assessment*

Schriftliche oder mündliche Abschlussprüfung

Literatur / *Literature*

- Holger Karl and Andreas Willig, Protocols and Architectures for Wireless Sensor Networks, Wiley, 2005

- Jie Wu, Handbook on Theoretical and Algorithmic Aspects of Sensor
- Ad Hoc Networks and Peer-to-Per Networks, Auerbach, 2005

Modul / *Module*
Echtzeitbetriebssysteme / Real-time Operating Systems

Nummer *Number*	11LE13MO-1217		
Modulverantwortlicher *Responsible person*	Prof. Dr. B. Becker, Prof. Dr. C. Scholl,	**Einrichtung** *Organisational unit*	Chair Rechnerarchitektur, Chair Betriebssysteme
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 Term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Knowledge in operation systems and technical computer science		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS: *Term week hours*	3 Lecture + 1 Exercises	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand: *Workload*	180 hours (56 Full-time attendance course of study + 124 Self-study)		

Lernziele / *Learning objectives*

The students are familiar with basic methods of real-time operating systems. In particular, they know the essential differences between standard operating systems and real-time operating systems for embedded systems both concerning requirements and concerning concepts of realization (especially in the area of scheduling). The students know basic functions of real-time operating systems and have experience with programming of real-time systems.

Inhalte Vorlesung / *Content of the lecture*

After a brief review of standard operating systems and the hardware requirements for the implementation of operating systems the lecture deals with operating systems for embedded systems and the question how real-time requirements can be fulfilled. In order to answer this question the lecture looks into methods which compute upper bounds to the run time of processes (“worst case execution times”) and into scheduling methods which guarantee meeting certain deadlines under the condition that the run times do not exceed given worst case execution times. Various scheduling approaches are classified with respect to their application area and analyzed with respect to their quality and cost. Moreover, the lecture looks into basic concepts like synchronization and communication of several processes, shared resources, mutual exclusion etc. together with their role in the design of real-time operating systems.

Zu erbringende Prüfungsleistung / *Course-based assessment*

written or oral examination

Literatur / *Literature*
Will be announced at the beginning of the course.

Modul / *Module*

Einführung in Embedded Systems / Introduction to Embedded Systems

Nummer *Number*	11LE13MO-910		
Modulverantwortlicher *Responsible person*	Prof. Dr. B. Becker, Prof. Dr. C. Scholl, Prof. Dr. van Laerhoven	**Einrichtung** *Organisational unit*	Lehrstuhl Rechnerarchitektur, Lehrstuhl Betriebssysteme, Lehrstuhl Eingebettete Systeme
Modultyp *Module type*	Wahlpflichtmodul	**Moduldauer** *Module duration*	1 Semester
Zugehörige Lehrveranstaltungen *Connected events*	Vorlesung und Übung	**Sprache** *Language*	Deutsch
Empfohlene Voraussetzungen *Recommended preconditions*	Wissen und Kenntnisse des vermittelten Lernstoffs des Moduls Technische Informatik		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	3 Vorlesung + 1 Übung	**Angebotsfrequenz** *Regular cycle*	nur im Wintersemester
Arbeitsaufwand *Workload*	180 Stunden (64 Stunden Präsenzstudium + 116 Stunden Selbststudium)		

Lernziele / *Educational objectives*

Die Studierenden haben ein grundlegendes Verständnis für die spezifischen Eigenschaften von Eingebetteten Systemen. Sie kennen die elementaren Konzepte zum Entwurf derartiger Systeme sowie Kriterien für die Partitionierung in Hardware bzw. Software. Sie kennen die Eigenschaften der Bauelemente eines Eingebetteten Systems und erfassen die daraus resultierenden Anforderungen an Schnittstellen und das Gesamtsystem. Sie sind in der Lage, die spezifischen Restriktionen, die sich durch die physikalischen Gesetze des umgebenden Systems ergeben, einzuschätzen und können diese gezielt in den Entwurfsprozess einbeziehen. Schließlich sind sie sich darüber im Klaren, wie spezifische Methoden aus der Softwaretechnik einerseits und dem Hardwareentwurf andererseits zu einer leistungsfähigen Entwurfsmethodik kombiniert werden können, die Anforderungen bzgl. Größe, Reaktionszeiten, Kosten und Energieverbrauch des resultierenden Gesamtsystems berücksichtigt.

Inhalte Vorlesung / *Content of the lecture*

Eingebettete Systeme gelten als die Schlüsselanwendung der Informationstechnologie in den kommenden Jahren und sind, wie der Name bereits andeutet, Systeme, bei denen Informationsverarbeitung in eine Umgebung eingebettet ist und dort komplexe Regelungs-, Steuerungs- oder Datenverarbeitungsaufgaben übernimmt.

Die Vorlesung beschäftigt sich mit grundlegenden Konzepten für Modellierung und Entwurf Eingebetteter Systeme. Sie behandelt u.a. Spezifikationssprachen und Methoden für Eingebettete Systeme (wie z.B. Statecharts, Petrinetze, VHDL), Abbildung von Spezifikationen auf Prozesse, Hardware Eingebetteter Systeme sowie Hardware-/Software-Codesign.
Es wird auf die Bauelemente eines Eingebetteten Systems eingegangen (z.B. Prozessoren, AD-/DA-Wandler, Sensoren, Sensorschnittstellen, Speicher) und es werden Methoden zum Entwurf und zur Optimierung der zugehörigen Schaltungen bezüglich Geschwindigkeit, Energieverbrauch und Testbarkeit vorgestellt.

Zu erbringende Prüfungsleistung / *Course-based assessment*

schriftliche oder mündliche Abschlussprüfung

Literatur / *Literature*

- Marwedel, P.: Embedded System Design. Springer-Verlag New York, Inc., 2006.
- Marwedel, P. ; Wehmayer, L.: Eingebettete Systeme. Springer-Verlag Berlin, 2007.
- Ritter, J. ; Molitor, P.: VHDL - Eine Einführung. Pearson Studium, 2004.
- Chang, K. C.: Digital Design and Modeling with VHDL and Synthesis. IEEE Computer Society Press, 1996.
- Teich, J. ; Haubelt, C.: Digitale Hardware/Software-Systeme. Berlin : Springer-Verlag Berlin, 2007.
- Baker, R. J.; Li, H. W.; Boyce, D. E.: CMOS Circuit Design, Layout, and Simulation. IEEE Press Series on Microelectronic Systems, 1998.
- Rabaey, J. M.; Chandrakasan, A. P.; Nikolic, B.: Digital Integrated Circuits. Prentice-Hall, 2003.
- Tietze, U.; Schenk, C.: Halbleiter Schaltungstechnik. Springer-Verlag, 2002.
- Weste, N.; Eshraghian, K.: Principles of CMOS VLSI Design; A Systems Perspective. Addison-Wesley, 1993.

Modul / *Module*
Electrochemical energy applications: Li-ion batteries and fuel cells / Elektrochemische Energieanwendungen: Li-Ionen-Batterien und Brennstoffzellen

Nummer *Number*	11LE50MO-5261		
Modulverantwortlicher *Responsible person*	Dr. Matthias Breitwieser, Dr. Severin Vierrath Prof. Dr. Zengerle	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English or German
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	None		

Empfohlenes Fachsemester *Recommended term of study*	-	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Irregularly
Arbeitsaufwand *Workload*	90 hours		

Lernziele / *Learning objectives*

Understanding of
- basic electrochemistry
- hydrogen fuel cell working principle, materials, systems
- Li-ion battery working principle, types, materials
- Next-generation batteries (Li-Air, solid electrolyte)
- Electrochemical and ex-situ characterization methods

Inhalte Vorlesung / *Content of the lecture*

Electrochemical energy systems such as Li-ion batteries or fuel cells play a major role in a future emission-free economy. This lecture gives a brief introduction into the basics of electrochemistry and discusses recent developments of Li-Ion batteries and hydrogen fuel cells. This includes novel materials, fabrication techniques and characterization methods.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written examination

Zu erbringende Studienleistung / *Coursework*

Literatur / *Literature*

Modul / *Module*
Elektrochemische Energieanwendungen / Electrochemical energy applications

Nummer *Number*	11LE50MO-5123		
Modulverantwortlicher *Responsible person*	S. Thiele	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	German
Empfohlene Voraussetzungen *Recommended preconditions*	None		

Empfohlenes Fachsemester *Recommended term of study*	2 - 4	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Irregularly
Arbeitsaufwand *Workload*	90 hours (32 hours Full-time attendance course of study + 58 hours Self-study)		

Lernziele / *Learning objectives*
The students have acquired an understanding of the relevance of electrochemical systems for the global energy transition. They are able to transfer basic electrochemical effects to different electrochemical systems. They understand the connections between electrochemical analysis methods and properties of the considered electrochemical systems. They are able to propose simple strategies for the improvement of electrochemical systems.

Inhalte Vorlesung / *Content of the lecture*
Electrochemical systems such as fuel cells, batteries or electrolysis cells are promising approaches for the global energy transition. Based on these examplaric electrochemical systems key electrochemical effects are taught in this course. Additionally partial thematic topics of the global energy transition such as electromobility or energy storage are discussed. Limitations and novel developments of the mentioned electrochemical systems are covered. Finally all important electrochemical characterisations methods are discussed and explained.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written examination

Literatur / *Literature*
Will be provided within the lecture.

Modul / *Module*

Elektrochemische Methoden für Ingenieure / Electrochemical Methods for Engineers

Nummer *Number*	11LE50MO-5719		
Modulverantwortlicher *Responsible person*	Prof. Dr. Gerald Urban	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Zwingende Voraussetzungen: *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Introductory lecture to chemistry or similar knowledge Introductory lecture to electronics or similar knowledge		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 hours		

Lernziele / *Learning objectives*

The students know the essential concepts and fundamental equations of electrochemical theory. The participants from different subjects link together the knowledge from physical chemistry and several engineering disciplines to get a sound understanding of the classical electrochemical methods and electrochemical impedance spectroscopy. The students can apply their knowledge and understanding of the electrochemical methods to tasks in the field of material science, microtechnology, microsystems and energy application.

Inhalte Vorlesung / *Content of the lecture*

- Electrochemical theory (cells, electrodes, fundamental equation and concepts)
- Instrumentation (focus on the interplay between electrochemistry and electronics/data acquisition), equipment (electrodes, cells), and electrolytes
- Classical methods (potentiometry, amperometry, CV, DPV, SWV, HDME, RDE, RRDE)
- Electrochemical impedance spectroscopy (EIS)
- Selected aspects: Material science (corrosion, hierarchical micro-/nanostructures)
- Selected aspects: Microtechnology (electrodeposition, failure mechanism)
- Selected aspects: Microsystems (electrochemical sensors and actuators)
- Selected aspects: Energy application (fuel cells, batteries, super caps)

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Zu erbringende Studienleistung / *Coursework*
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Literatur / *Literature*
• Bard, Faulkner: Electrochemical Methods – Fundamentals and Applications, 2nd ed., 2001, Wiley, library: SB/I.1/1 • Hamann, Hamnett, Vielstich: Electrochemistry, 2nd ed., Wiley-VCH 2007, library: SB/H.2/13 • Zoski: Handbook of electrochemistry, 1st ed., Elsevier, 2007, available as ebook (campus license)

Modul / *Module*
Elektromobilität / Electromobility

Nummer *Number*	11LE68MO-4111		
Modulverantwortlicher *Responsible person*	M. Vetter	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*		**Sprache** *Language*	English
Voraussetzungen zwingend *Preconditions mandatory*	Lecture and exam in energy storage		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	75h		

Lernziele / *Learning objectives*

- Know-how in various aspects and concepts of electro-mobility for automotive applications (light electric vehicles LEV, electric vehicles EV, plug-in hybrid electric vehicles PHEV), public transport, light and heavy load transport, marine sector as well as aerospace sector.
- Know-how in electrical storage technologies for mobile applications.
- Know-how in system design for mobile applications including peripheral components.
- Know-how in infrastructure concepts and challenges (e.g. fast charging stations).

Inhalte Vorlesung / *Content of the lecture*

- Electromobility in various sectors: Automotive, public transport, marine sector, aerospace, etc.
  - o System concepts
  - o Typical system designs
  - o Infrastructure challenges and solutions
- Overview on relevant electric storage technologies for electromobility
- Storage system design for various mobile applications: module design, electrical, thermal and mechanical interconnections, thermal management, storage management, integration of peripheral components
  - o Safety aspects and criteria
  - o Environmental issues

Zu erbringende Prüfungsleistung / *Course-based assessment*

oral examination

Literatur / *Literature*
• STATUS ELECTROMOBILITY 2016: OR HOW TESLA WILL NOT WIN, Prof. Dr.-Ing. Markus Lienkamp. • G. Pistoia: Lithium-Ion Batteries Advances and Applications.

Modul / *Module*

Eingebettete Regelungssysteme Praktikum / Embedded Control Laboratory

Nummer *Number*	11LE50MO-5251		
Modulverantwortlicher *Responsible person*	M. Diehl	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*		**Sprache** *Language*	German or English (alternating)
Empfohlene Voraussetzungen *Recommended preconditions*	Systemtheorie und Regelungstechnik 1 / Systems and Control 1, Systemtheorie und Regelungstechnik 2 / Systems and Control 2, Modellierung und Systemidentifikation / Modelling and System Identification		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2	**Angebotsfrequenz** *Regular cycle*	Irregularly in summer term
Arbeitsaufwand *Workload*	90 hours (28h attendance + 62h self-study)		

Lernziele / *Learning objectives*

Students are able to model and to simulate a mechatronic system and to design a feedback controller. In particular, they learn how to perform model based controller design and to use a rapid control prototyping approach.

Die Teilnehmenden erlernen für die industrielle Praxis wichtige Fähigkeiten in der Modellierung und der Entwicklung eingebetteter Regelungssysteme. Sie sind in der Lage ein mechatronisches System zu modellieren sowie eine Regelung für das entwickelte System zu entwerfen. Insbesondere lernen die Studierenden den modellbasierten "Rapid Control Prototyping"-Entwicklungsansatz anzuwenden und verschiedene regelungstechnische Verfahren in der Praxis anzuwenden und zu beurteilen.

Inhalte Vorlesung / *Content of the lecture*

Students model an existing mechatronic system. The control is realized via a „Rapid Control Prototyping“ (RCP) system. The physical system will first be modelled, and the controller will be designed, tested, and tuned with help of computer simulations, until a desired specificatin is met. The control algorithm will then be directly deployed to a an existing control hardware of the RCP system, without the need of further programming.

Die Studierenden modellieren ein existierendes mechatronisches Regelungssystem. Die Regelung wird mittels eines „Rapid Control Prototyping“-Ansatzes (RCP) realisiert. Dazu wird das zu regelnde System modelliert und darauf aufbauend der Regler mit Hilfe von Computersimulationen entworfen, getestet und verfeinert bis eine hinreichende

Regelungsgüte in der Simulation erreicht ist. Der gefundene Regelungsalgorithmus wird zum Einsatz im realen Aufbau direkt aus der Simulationsumgebung auf eine existierende Steuerungshardware geladen, die zur echtzeitfähigen Realisierung in der Zielhardware keiner weiteren Programmierung bedarf.

Zu erbringende Prüfungsleistung / *Course-based assessment*
written or oral examination

Zu erbringende Studienleistung / *Coursework*
written or oral examination

Benotung / *Grading*
The module grade is calculated from the result of the final examination.

Gewichtung der Prüfungsleistung / *Weight of Course-based assessment*
Master of Science in Sustainable Systems Engineering, Academic regulations of 2016: The grade of the module is single-weighted according to the number of its ECTS credits in the calculation of the overall grade.

Literatur / *Literature*
Will be made available to participants at the start of the project.

Modul / *Module*
Energie in Gebäuden: Energiebedarf und bauphysikalische Grundlagen **Energy in Buildings: energy demand and building physics**

Nummer: *Number*	11LE68MO-4112-ab042019		
Modulverantwortlicher: *Responsible person*	Prof. Dr. H.-M. Henning, Dr. S. Hess, B. Rodenbücher	**Einrichtung:** *Organisational unit*	INATECH
Modultyp: *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen: *Connected events*	lecture and practical exercise	**Sprache:** *Language*	English
Empfohlene Voraussetzungen: *Recommended preconditions*	Energy Storage, Solar Energy		
Zwingende Voraussetzungen: *Mandatory requirements*	none		

Empfohlenes Fachsemester:: *Recommended term of study*	2	**ECTS-Punkte:** *ECTS credits*	6
SWS: *Semester week hours*	4	**Angebotsfrequenz:** *Regular cycle*	Summer term
Arbeitsaufwand: *Workload*	180 hours (total incl. preparation and lecture attendance)		

Verwendbarkeit der Veranstaltung / *Usability of the module*
Elective Module for students of the study program • Master of Science in Sustainable Systems Engineering: Energy Systems

Lernziele / *Learning objectives*
The students know the influencing factors on the energy demand of buildings. They know about the requirements and prerequisites for low energy and passive houses. They are familiar with methods for setting up energy balances for buildings and the relevant technical indoor equipment. Students are able to judge under which circumstances zero-energy or plus-energy buildings (with respect to the annual primary energy balance) are attainable. They know the requirements and criteria for indoor comfort in buildings and they are able to estimate the influence of different renovation and retrofit measures on the energy demand

and indoor comfort. They know use cases and limits of different heat transfer systems for heating and cooling of indoor environments and are familiar with low exergy concepts for building energy systems.

Inhalte Vorlesung / *Content of the lecture*

- Selected chapters of building physics regarding energy demand of buildings for heating and cooling
- Indoor comfort in buildings
- Ventilation demand and ventilation concepts
- The passive house concept
- Passive use of solar energy in buildings; physics of transparent building components
- Passive systems / concepts for cooling of buildings
- Exergetic evaluation of building systems
- Heat transfer systems to rooms for heating and cooling
- Efficient energy conversion chains, „low-ex“ systems

Inhalte Praktische Übung / *Content of the practical exercise*

The lecture will be accompanied by a weekly exercise to deepen the understanding of the lecture's content and to discuss further details. The practical exercise includes calculations, practical experiments (e.g. on thermal insulation and optical properties), system simulations (with polysun) and/or case studies.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written supervised exam

Zu erbringende Studienleistung / *Coursework*

- Active participation / attendance 85% during exercises.
- Written documentation.

Literatur / *Literature*

Energy Performance of Buildings - Energy Efficiency and Built Environment in Temperate Climates. Editors: Boemi, Sofia-Natalia, Irulegi, Olatz, Santamouris, Mattheos (Eds.). Springer. ISBN 978-3-319-20831-2

Modul / *Module*

Energie in Gebäuden: Komponenten und Systeme der Energieversorgung
Energy in Buildings: components and systems for energy supply

Nummer *Number*	11LE68MO-4113-ab102019		
Modulverantwortlicher *Responsible person*	Prof. Dr. H.-M. Henning, Dr. Stefan Hess, Beatrice Rodenbücher	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and practical exercise	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Energy Storage, Solar Energy, Energy in Buildings: energy demand and building physics		
Zwingende Voraussetzungen *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6 (as of winter term 2019!)
SWS *Semester week hours*	4	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	180 hours		

Lernziele / *Learning objectives*

The students know important technical components for energy supply (heating, cooling, air dehumidification) of buildings. Classical processes such as gas burners and compression chillers are covered as well as processes involving renewable energy (especially solar energy and ambient heat). The students are familiar with the physical principles of these processes and are able to derive key figures of merit from these principles. They are aware of the state of the art in these technologies and they can describe focal points of recent research and development work in this field. They are able to assess and compare different energy supply systems for buildings based on economic, ecologic and energy related figures of merit. They are also familiar with some basic methodologies for economic assessment of technical systems (life cycle cost assessment).

Inhalte Vorlesung / *Content of the lecture*

Covered technologies:
- Burners, condensing boiler technology
- Combined heating and power (CHP) units for buildings
- Heat transformation: principles, compression, absorption, adsorption

- Solar energy utilization: principles, solar thermal collectors, photovoltaics applied in buildings
- Energy storage: thermal storage, electrical storage and their system integration

Beside the technologies overall systems are analysed and specific figures of merit to assess different technical solutions are defined and applied. Basic methods for cost assessment as well as methods to assess building sustainability are presented and discussed.

Inhalte Praktische Übung / *Content of the practical exercise*

The lecture will be accompanied by a weekly exercise to deepen the understanding of the lecture's content and to discuss further details. The practical exercise includes calculations and system simulations (with polysun).

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written supervised exam

Zu erbringende Studienleistung / *Coursework*

- Attendance during the practical exercise is required (minimum 85 % attendance)
- Work on (weekly) exercise sheets
- Written documentation

Literatur / *Literature*

Ursula Eicker: Solar Technologies for Buildings. Springer. ISBN-13: 978-0471486374

Solar Cooling Handbook 3rd Revised & enlarged Edition. by Hans-Martin Henning (Editor), Mario Motta (Editor), Daniel Mugnier (Editor). Ambra. ISBN-13: 978-3990434383

Modul / *Module*
Energy Economics / Energiewirtschaft

Nummer *Number*	11LE68MO-5561		
Modulverantwortlicher *Responsible person*	Prof. Dr. Anke Weidlich	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Mandatory module: Control and Integration of Grids		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte:** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term; **as of winter 2019; cannot be combined with former module EEEP**
Arbeitsaufwand *Workload*	90 hours (approx. 24 h attendance, approx. 66 h exercises and preparation for exam)		

Lernziele / *Learning objectives*

The students know and understand the structure of an energy sector for the example of Germany, and are able to systematically assess the structures of other energy markets. They can name different energy policy instruments and explain their working mechanism. They understand the impact of current developments in regulation and policy on the energy sector. The students are able to perform economic calculations that help to assess the profitability of investments in the energy sector. They are able to critically assess energy scenarios. They know about the functioning of different energy markets and their possible future developments with rising shares of renewable energy.

Inhalte Vorlesung / *Content of the lecture*

- Structure of the energy sector and terminology (national energy balances; regulation principles; market roles; specifics of grid-bound energy sectors)
- Cost calculations; learning curves; investment appraisal methods
- Electricity markets and market coupling; economics of cogeneration; marketing of renewable energy; sector coupling
- Energy policy and environment protection instruments

Zu erbringende Prüfungsleistung / *Course-based assessment*

- Written supervised exam

Zu erbringende Studienleistung / *Coursework*

- None; exercise sheets will be offered for practice on a voluntary basis

Benotung / *Grading*

The module grade will be based on the written supervised exam (100%).

Literatur / *Literature*

- P. A. Narbel, J. P. Hansen and J. R. Lien: Energy Technologies and Economics, Springer International Publishing Switzerland, 2014.
- Konstantin, P., Konstantin, M.: Power and Energy Systems Engineering Economics Best Practice Manual, Springer, 2018.

Modul / *Module*
Engineering of Functional Materials / Technische Funktionswerkstoffe

Nummer *Number*	11LE68MO-4222		
Modulverantwortlicher *Responsible person*	Prof. Dr.-Ing. Frank Balle, Michael Becker, Florian Staab	**Einrichtung** *Organisational unit*	INATECH-EFM
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture + Laboratory	**Sprache** *Language*	German
Empfohlene Voraussetzungen *Recommended preconditions*	Grundlagenwissen im Bereich der Materialwissenschaft und Werkstoffkunde (Bachelor-Studium)		
Zwingende Voraussetzungen *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** ECTS credits	6
SWS *Semester week hours*	4	**Angebotsfrequenz** Regular cycle	Summer term; max 20 participants
Arbeitsaufwand *Workload*	180h		

Lernziele / *Learning objectives*
In diesem Modul sollen die Studierenden werkstoffkundliche Grundlagen auffrischen bzw. vertiefen, um Ingenieurwerkstoffe für technische Anwendungen bewerten zu können. Sie sind somit in der Lage relevante Anforderungsprofile für technische Funktionswerkstoffe zu formulieren und hinsichtlich deren Wichtigkeit zu priorisieren. Sie lernen wichtige Prozesse und Verarbeitungsverfahren für Ingenieurwerkstoffe können incl. den Vor- und Nachteilen ausgewählter technischer Funktionswerkstoffe und sind in der Lage Möglichkeiten zur gezielten Beeinflussung (multi-) funktionaler Werkstoffeigenschaften zu erläutern. Darüber erlernen die Studierenden anhand ausgewählter Beispiele Nachhaltigkeitsaspekte von aktuellen Werkstofflösungen und deren Prozesstechnik für Ingenieuranwendungen. Die theoretischen Inhalte werden durch praktische Versuche im Labor flankiert und vertieft.

Inhalte Vorlesung / *Content of the lecture*
Die Veranstaltung baut auf den materialwissenschaftlichen Grundlagen zum Aufbau der Struktur und den resultierenden Eigenschaften von Ingenieurwerkstoffen auf. Anschließend

werden ingenieurwissenschaftliche Anforderungen an Technische Funktionswerkstoffe erarbeitet – insbesondere im Hinblick auf Nachhaltigkeitsaspekte. Es werden ausgewählte Werkstoffsysteme in Bezug auf deren Hauptanforderungen besprochen wie Werkstoffe mit Leitfunktion, Isolierfunktion, magnetischen und dielektrischen Funktionen. Darüber hinaus werden technisch relevante Prozesse für Ingenieurwerkstoffe mit spezifischem Anforderungsprofil vorgestellt. Dieser Themenkomplex umfasst Lehrinhalte und Anwendungsszenarien von Funktionswerkstoffen bzw. Funktionsschichen hinsichtlich Korrosionsschutz, Oxidationsschutz und Verschleißschutz als auch Werkstoffe zur Fertigungs- und Bearbeitungstechnik sowie Verbindungstechniken für Technische Funktionswerkstoffe. Im letzten Teil der Vorlesung werden multifunktionale Werkstoffkonzepte, zumeist auf Basis von Verbundwerkstoffen oder hybriden Werkstoffen bzw. Strukturen behandelt, die neben strukturellen Vorteilen insbesondere verschiedene Funktionen in einem System vereinen.

Inhalte Praktische Übung / *Content of the Laboratory*

Die Praktische Übung greift ausgewählte Themen und vorgestellte Methoden zur Charakterisierung, Bewertung und auch Verarbeitung von Ingenieurwerkstoffen auf und wird begleitend zur Vorlesung “Technische Funktionswerkstoffe” angeboten. Die Studierenden haben die Möglichkeit forschungs- und anwendungsrelevante Werkzeuge und Methoden praktisch kennen zu lernen, um den theoretisch erlernten Hintergrund zu erleben und somit zu untermauern.
Die Praktische Übung setzt sich aus verschiedenen materialwissenschaftlichen Einzelversuchen zusammen, zu deren Vorbereitung jeweils eine Einführungsveranstaltung angeboten wird. Zu Beginn jedes Versuches findet ein mündliches Kolloquium statt, um die notwendigen Grundlagen zur Versuchsdurchführung sicherzustellen. Dieses Kolloquium muss von allen Teilnehmer bestanden werden, um am Versuch erfolgreich teilnehmen zu dürfen. Es besteht die Möglichkeit maximal 2 Versuche zu wiederholen. Die Praktische Übung gilt als bestanden, wenn alle (max. 8) Versuche erfolgreich absolviert wurden.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Mündliches Prüfungsgespräch über die Inhalte aus der Vorlesung und der Praktischen Übung (Modulabschlussprüfung). Es sind keine Hilfsmittel zugelassen.

Zu erbringende Studienleistung / *Coursework*

100% Anwesenheit in der Praktischen Übung und erfolgreiches Absolvieren des Praktischen Übung: Zu Beginn jedes Versuches findet ein mündliches Kolloquium statt, um die notwendigen Grundlagen zur Versuchsdurchführung sicherzustellen. Dieses Kolloquium muss von allen Teilnehmern bestanden werden, um am Versuch erfolgreich teilnehmen zu dürfen. Es besteht die Möglichkeit maximal 2 Versuche zu wiederholen. Die Praktische Übung gilt als bestanden, wenn alle (max. 8) Versuche erfolgreich absolviert wurden.

Literatur / *Literature*

- W. Bergmann: Werkstofftechnik 1 und 2, Carl Hanser Verlag, 2008 / 2009
- M. Bäker: Funktionswerkstoffe, Springer Vieweg Verlag, 2014
- G. Gottstein: Materialwissenschaft und Werkstofftechnik, Springer Vieweg Verlag, 2014

- H. Hofmann, J. Spindler: Werkstoffe in d. Elektrotechnik, Carl Hanser Verlag, 2013
- E. Macherauch, W. Zoch: Prakitkum in Werkstoffkunde, Springer Vieweg Verlag, 2014

Modul / *Module*

Environmental Psychology for Engineers

Nummer *Number*	11LE68MO-5556-ab102019		
Modulverantwortlicher *Responsible person*	Dr. S. Gölz, Jessica Berneiser	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Seminar	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6 (as of winter term 2019)
SWS *Semester week hours*	2	**Angebotsfrequenz** *Regular cycle*	Irregularly in winter term; limited number of seats
Arbeitsaufwand *Workload*	180 hours (of which 30h for attendance)		

Lernziele / *Learning objectives*

Upon successful completion of this module, students should be able to:
(1) Orient themselves among existing theories of environmental psychology.
(2) Apply psychology theories and models to real-world settings.
(3) Elaborate basic designs for environmental interventions.
(4) Use environmental psychology methodologies in complex transformation settings.
(5) Present/discuss a selected topic / paper.

Inhalte Vorlesung / *Content of the lecture*

Human behaviour is a key factor for current global economic and ecological challenges. On the other hand, it is also a crucial resource which can be used to cope with these challenges. Environmental Psychology is an interdisciplinary field focusing on how human behavior and the physical environment interrelate. In the perspective of sustainable transformation, human behavior is crucial This course will introduce the basic elements of Environmental psychology.

In the course, students will study psychological theories and modelling and will become familiar with typical issues in applied fields of environmental psychology (such as the attitudes-behavior gap, behavior in social dilemmas,, interventions and behavioral changes. As different technological innovations (e.g. e-mobility and renewable energies) promise improvement for ecological risks, environmental psychology approaches for the domain of technology usage, acceptance and usability will be addressed.

Course units in detail (may be subject to change):
• What is environmental behavior / Models explaining environmental behavior
• Changing behavior- Models and approaches
• Factors influencing environmental behavior I – Values & Social norms

• Factors influencing environmental behavior II – Symbolic and affective aspects
• Nasty challenges I – Habits
• Encouraging pro-environmental behavior I – Informational strategies & Rewards and penalties
• Encouraging pro-environmental behavior III – Persuasive technology
• Diffusion of innovative technologies (Renewable technologies, e-mobility)
• Social reactions to technology innovation and transformations: What we call acceptance

Zu erbringende Studienleistung / *Coursework*

- Attendance at the seminar is mandatory (85%)
- Written and practical work
- Oral presentation

Details will be defined during first seminar.

Studierende bearbeiten kursbegleitend in Kleingruppen eine praktische umweltpsychologische Fragestellung (gerne eigene Ideen), bei der entweder eine Massnahme oder ein Survey aus umweltpsychologischen Gesichtspunkten konzipiert und umgesetzt wird. In dieser kursbegleitenden Praktikumsarbeit leiten die Studierende den Transfer des im Kurs vermittelten Stoffs und setzen ihn praktisch um.
Folgende Studien müssen im Rahmen des Kurses und der kursbegleitenden Praktikumsarbeit erbracht werden:
- Regelmässige Kursteilnahme und Lesen der Pflichttexte (ca. 60h)
- Durchführung einer kursbegleitenden Praktikumsarbeit in Kleingruppen mit Erstellung von Protokollen zu den Gruppentreffen (mit Kennzeichnung der Leistungen der einzelnen Gruppenteilnehmern), Erstellung einer Zwischen- und Abschlusspräsentation in der Gruppen, sowie eines persönlichen Reflectionpapers, in dem der Transfer aus dem Kurs und den Hausaufgaben auf die Praktikumsarbeit verdeutlicht wird (120h).

Literatur / *Literature*

- Steg, L., Van den Berg, A.E., De Groot, J., (2013). Environmental Psychology: An Introduction. London: BPS Blackwell.
- Hamann, K. Baumann, A. Löschinger, D. (2017). Psychology of Environmental Protection – Handbook for Encouraging Sustainable Actions. München: oekom

Modul / *Module*
Ergebnisse wissenschaftlich präsentieren / Scientific writing and presentation

Nummer *Number*	11LE50MO-5801SL		
Modulverantwortlicher *Responsible person*	Prof. Dr. T. Hanemann	**Einrichtung** *Organisational unit*	IMTEK, Chair Werkstoffprozess-technologien
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen: *Connected events*	Seminar	**Sprache** *Language*	German or English

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Seminar	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90 hours (28 hours Full-time attendance course of study + 58 hours Self-study)		

Lernziele / *Learning objectives*

Die Studierenden werden
- über die Bedeutung der Einhaltung der guten wissenschaftlichen Praxis informiert
- in die Lage versetzt, ein Labortagebuch (Laborjournal) und einfache wissenschaftliche Berichte zu schreiben
- über das Erstellen einer Master- bzw. Promotionsarbeit informiert
- in die Lage versetzt, einen wissenschaftlichen Vortrag (15 min), einen Kurzvortrag (3 min), ein wissenschaftliches Poster sowie ein Werbeposter zu erstellen und zu präsentieren.

Inhalte Vorlesung / *Content of the lecture*

The following topics will be covered during the course:
- Ancient and current scientific malpractice
- Rules for safeguarding good scientific practice
- Laboratory journal, Scientific reports (from project reports to dissertation thesis)
- Lecture presentation
- Oral poster presentation (3 minutes lecture)
- Scientic poster presentation, "Advertisement" poster

Zu erbringende Studienleistung / *Coursework*

Written or oral examination

Modul / *Module*

Funktionale Sicherheit: Aktive Resilienz / Functional Safety: Active Resilience

Nummer *Number*	11LE68MO-5120		
Modulverantwortlicher *Responsible person*	I. Häring	**Einrichtung:** *Organisational unit*	INATECH
Modultyp *Module type*	Elective module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*		**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Grundlagen in den Bereichen Systemmodellierung, Systemanalyse, Zuverlässigkeitsbewertung oder Sicherheitsbewertung für eine ausgewählte technische Fachdisziplin wären hilfreich, insbes. Elektrotechnik oder Informatik. Any basics in the areas of system modelling, system analysis, reliability or safety assessment for a selected technical discipline would be appreciated, in particular electronics and informatics.		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90 h (28 Anwesenheit / attendance + 62 Selbststudium / self-study)		

Lernziele / *Learning objectives*

Lernziele umfassen die anwendbare Kenntnis des Konzepts Sicherheit und Resilienz von Systemen mit Hilfe von ausreichend zuverlässigen aktiven Systemfunktionen aufrechtzuerhalten bzw. herzustellen, sowie entsprechender grundlegender Vorgehens-, Entwicklungs- und Nachweisprozesse. Ferner wie diese Prozesse mit Hilfe von Techniken und Maßnahmen und ihrer effizienten Kombination unterstützt werden sowie welche Kennzahlen hierfür grundsätzlich eingesetzt werden können. Weitere Lernziele sind Überblickswissen zu den häufigsten in der Praxis verwendeten Techniken und Maßnahmen sowie modernere Erweiterungen und neuere Methoden. Im Bereich der fachspezifischen Methoden, im Gegensatz zu allgemein auf Systeme anwendbaren Methoden, liegt der Schwerpunkt auf Systemen, die auch Elektronikhardware und Software verwenden. Ferner soll begleitend ein Überblick über aktuellere Anwendungsbeispiele (z. B. autonome Fahrfunktionen, Mensch-Roboter Kollaboration) sowie die sich entwickelnde Normenlandschaft erworben werden.

Learning objectives include the applicable knowledge of the concept of maintaining or generating safety, security and resilience of systems by means of sufficiently reliable active system functions as well as the corresponding basic procedure, development and verification and validation processes. Furthermore, how these processes are supported by techniques and measures and their efficient tailoring and combination as well as which

technical quantities are typically used. Other learning objectives are to know the most practically used techniques and measures as well as modern extensions and newer methods. In the area of disciplinary specific methods, as opposed to generally on systems applicable methods, the focus is on methods that also use electronic hardware and software. Accompanying the students gain an overview on more recent application domains and examples (e. g. autonomous driving functions) as well as the developing standardization landscape.

Inhalte Vorlesung / *Content of the lecture*

Hauptinhalte umfassen:
1. Grundlagen und Definition der funktionalen Sicherheit
2. Zusammenhang Funktionale Sicherheit, Resilienz, Safety und Security: Definition Resilienzfunktion
3. Sicherheitslebenszyklusmodelle, allgemeine Anforderungen und Anforderungen an die Phasen
4. Analysemethoden und ihre Kombination zur Identifikation und Festlegung von Sicherheits- und Resilienzfunktionen, insbes. induktive (z. B. HL, HA, ETA, DFM), deduktive (z. B. FTA) analytische Methoden, graphische, algebraische und semi-formale sowie ihre geeignete Kombination
5. Methoden zur Allokation der Funktionen bzw. zur Festlegung von funktionalen Sicherheits- und Resilienzdesigns
6. Quantitative Kenngrößen (z. B. SIL, HFT, DC, DD, DU)
7. Überblick Methoden für Hardware und Software
8. Überblick neuere und neue Methoden (z. B. TFTA, Markovmodelle und –prozesse)
9. Anwendungsbereiche und -beispiele
10. Normenlandschaft

Main contents comprise:
1. Fundamentals and definition of functional safety
2. Relation of functional safety to resilience, safety and security: definition of resilience functions
3. Safety lifecycle models, general and phase-specific requirements
4. Analytical methods and their combination for the identification and determination of safety and security resilience functions, especially inductive (e.g. HL, HA, FMEDCA, ETA, DFM), deductive (e.g. FTA) analytical methods, graphical, algebraic and semi-formal
5. Methods for the allocation of safety functions and generation of functional safety and resilience designs
6. Quantities for functional safety (e.g. HR, SIL, DC, DD, DU)
7. Methods for hardware and software
8. Method extensions and emerging methods (e.g. TDFT, Markov models and processes)
9. Application domains and examples
10. Standardization landscape

Zu erbringende Prüfungsleistung / *Course-based assessment*

written or oral examination

Literatur / *Literature*

Example literature/ Sample literature:
Satisfying safety goals by probabilistic risk analysis, Hiromitsu Kumamoto, Springer 2007
Modern statistical and mathematical methods in reliability, Alyson Wilson et. al. (eds.), World

Scientific, 2005
Mathematical and statistical methods in reliability, Bo H Lindqvist and Kyell A Doksum, World Scientific, 2003
Elektronische Sicherheitssysteme, Josef Börcsök, Hüthig, 2004
Funktionale Sicherheit: Grundzüge sicherheitstechnischer Systeme, Hüthig, 2014
Zuverlässigkeitstechnik, Arno Meyna and Bernhard Pauli, Hanser, 2010
The safety critical systems handbook, David J. Smith, Butterworth-Heinemann, 2010
Funktionale Sicherheit im Automobil, Hans-Leo Ross, Hanser, 2014
FRAM: the functional resonance analysis method, Erik Holnagel, Ashgate, 2012
Control systems safety evaluation and reliability, William M. Gobe, 2010

Further information:
http://www.iec.ch/about/brochures/pdf/technology/functional_safety.pdf

Modul / *Module*

Faserverbundwerkstoffe / Composite Materials

Nummer *Number*	11LE68MO-4209		
Modulverantwortlicher *Responsible person*	Dr. Michael May	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Participation in the module "Physics of failure" Participation in the module "Dynamics of materials"		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90h		

Lernziele / *Learning objectives*

The educational objective of this course is to develop an understanding of the properties of composite materials. Aside high-performance materials, special emphasis is given to bio-based composite materials and their potential applications. The students will learn to predict the characteristic properties of composite materials. Additionally, the students will understand and describe damage and failure behavior of composites.

Das primäre Lernziel dieser Veranstaltung ist ein grundlegendes Verständnis für Faserverbundwerkstoffe zu schaffen. Besonderes Augenmerk liegt dabei - neben Hochleistungswerkstoffen - auf biobasierten Verbundwerkstoffen und deren Anwendungsmöglichkeiten. Die Kursteilnehmer werden lernen, die charakteristischen Eigenschaften von Verbundwerkstoffen zu prognostizieren. Zusätzlich wird Wissen über das Schädigungs- und Versagensverhalten von Verbundwerkstoffen vermittelt.

Inhalte Vorlesung / *Content of the lecture*

Composite materials offer high potential for the development of sustainable engineering structures. On the one hand, due to their unique material properties, composite materials are of particular interest for high-performance lightweight structures (e.g. modern aircraft) or structures requiring a certain amount of durability, such as wind turbines or marine turbines. On the other hand, the use of renewable natural resources (natural fibers, bio-polymers) in composite materials could be a path towards more sustainable consumption of limited resources such as oil.

In the first part of this course, the students will gain knowledge about typical anisotropic properties of high-performance composite materials. The students will learn approaches to estimate the mechanical properties of composite materials based on the constituents as well as approaches to determine the properties of a composite layup based on the properties of a single ply. Composite specific damage and failure mechanisms are discussed; experimental characterization and modeling approaches are described.
The second part of this course specifically covers composite materials made from renewable natural resources. Here, the students will learn about the potential and limitations of bio-based composites. The participants will learn about different types of natural constituents and their properties as well as the special behavior of their composites.

Faserverstärkte Kunststoffe (FVK) eignen sich hervorragend für die Entwicklung nachhaltiger Ingenieurstrukturen. Einerseits sind FVKs auf Grund ihrer einzigartigen Materialeigenschaften von besonderem Interesse für Hochleistungsleichtbaustrukturen (wie z.B. moderne Flugzeuge) oder Strukturen, welche eine lange Lebensdauer aufweisen, wie z.B. Windturbinen oder Gezeitenkraftwerke. Andererseits können durch den Einsatz erneuerbarer natürlicher Rohstoffe (Naturfasern, Biopolymere) Verbundwerkstoffe geschaffen werden, welche begrenzte natürliche Ressourcen wie z.B. Erdöl, schonen.
Im ersten Teil dieser Vorlesung werden die typischen anisotropen Eigenschaften von Hochleistungsverbundwerkstoffen vermittelt. Lehrinhalte sind insbesondere Ansätze zu Abschätzung der mechanischen Eigenschaften von Verbundwerkstoffen basierend auf den Eigenschaften der Konstituenten sowie Berechnungsansätze zur Bestimmung der Eigenschaften eines Laminats basierend auf den Eigenschaften der Einzellagen. Verbundwerkstoffspezifische Schädigungs- und Versagensmechanismen werden diskutiert; Experimentelle Charakterisierungsmöglichkeiten sowie Modellierungsansätze werden vorgestellt.
Der zweite Teil der Vorlesung beschäftigt sich explizit mit Verbundwerkstoffen auf Basis nachwachsender Rohstoffe. Das Potential dieser Werkstoffe wird ebenso dargestellt wie mögliche Hinderer. Die Teilnehmer werden verschiedene Arten natürlicher Ausgangsrohstoffe besprechen sowie Fertigungsmethoden und thermo-mechanische Eigenschaften dieser speziellen Materialklasse kennenlernen.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination

Zu erbringende Studienleistung / *Coursework*

If any, they will be announced during the first lecture.

Literatur / *Literature*

Isaac M. Daniel, Ori Ishai: Engineering Mechanics of Composite Materials, second edition, Oxford University press, ISBN-13: 978-0195150971

Wirasak Smitthipong, Rungsima Chollakup, Michel Nardin (Eds.): Bio-based composites for high-performance materials - from strategy to industrial application, CRC press, ISBN: 978-1-4822-1448-2

Modul / *Module*

Hardware Security and Trust

Nummer *Number*	11LE13MO-1227		
Modulverantwortlicher *Responsible person*	Prof. Dr. Bernd Becker	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	German or English
Zwingende Voraussetzungen: *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Kenntnisse in / Knowledge of • Technische Informatik • Rechnerarchitektur / Computer Architecture • Test und Zuverlässigkeit / Test and Reliability		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte:** *ECTS credits*	6
SWS *Semester week hours*	4	**Angebotsfrequenz** *Regular cycle*	Irregularly
Arbeitsaufwand *Workload*	180 hours		

Lernziele / *Learning objectives*

Die Studierenden kennen die grundlegenden Probleme und Fragestellungen im Bereich "Hardware Security and Trust", verstehen korrespondierende algorithmische Techniken, können sie anwenden und an neue Anforderungen anpassen. Für einen konkreten Entwurf kennen sie state-of-the-art Angriffsszenarien und sind in der Lage, Gegenmaßnahmen zu ergreifen, sie (sofern möglich) in das Design zu integrieren und Vor- und Nachteile dieser Maßnahmen zu beurteilen.

Inhalte Vorlesung / *Content of the lecture*

Die Konvergenz von IT-Systemen, Datennetzwerken und allgegenwärtigen eingebetteten Geräten in sogenannten Cyber Physical Systems hat zum Entstehen neuer Sicherheitsbedrohungen und -anforderungen im Zusammenhang mit der System-Hardware geführt. Die Manipulation von Hardware-Komponenten, die Sicherheitsfunktionen implementieren, kann die Systemintegrität beeinträchtigen, unautorisierten Zugang zu geschützten Daten ermöglichen und geistiges Eigentum (Intellectual Property) gefährden. Diese Gefährdungen zu adressieren, ist wesentlich, wenn verhindert werden soll, dass Hardware zur Schwachstelle des gesamten Systems wird. Zumindest ein Grundlagenwissen in "Hardware Security and Trust" ist wichtig für jeden Systemingenieur.

Zu Beginn werden die (notwendigen) Grundlagen über Kryptographie, Authentifizierung, Secret Sharing, VLSI Entwurf, Test, Zuverlässigkeit und Verifikation gelegt. Dann erfolgt eine Einführung in "Hardware Security and Trust", bei der folgende Themen angesprochen

werden: Physical and invasive attacks, side-channel attacks, physically unclonable functions, hardware-based true random number generators, watermarking of Intellectual Property (IP) blocks, FPGA security, passive and active metering for prevention of piracy, access control, hardware Trojan detection and isolation in IP cores and integrated circuits (ICs).

Inhalte Übung / *Content of the exercises*
Übungen vertiefen Methoden und Algorithmen, die in der Vorlesung eingeführt wurden, anhand von praktischen Beispielen.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Zu erbringende Studienleistung / *Coursework*

Literatur / *Literature*
Introduction to Hardware Security and Trust Editors: Tehranipoor, Mohammad, Wang, Cliff (Eds.), Springer

Modul / *Module*

Höchstleistungsrechnen mit Python / High-Performance Computing with Python

Nummer *Number*	11LE50MO-5253		
Modulverantwortlicher *Responsible person*	L. Pastewska, A. Greiner	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen: *Connected event*		**Sprache** *Language*	English or German
Zwingende Voraussetzungen *Mandatory requirements*	Knowledge of a programming language (not necessarily Python, i.e. Java, C, C++, etc.)		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	2 lecture + 2 project	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	180 Hours (64 full-time attendance course of study + 116 self-study)		

Lernziele / *Learning objectives*

The student
- can use Python for solving numerical problems using the numpy and scipy libraries and know strategies for writing efficient code
- can apply the Message Passing Interface (MPI) libraries to parallelize specific numerical problems
- can use job submission systems on parallel computers to run their Python codes.

Inhalte Vorlesung / *Content of the lecture*

This lecture teaches Python basics and fast array operations with the numpy library for numerical problems. Parallelization strategies using the Message Passing Interface will be discussed.

1. Python basics: Containers, flow controls, functions
2. Python numerics: numpy arrays, numpy operations, scipy
3. Parallelization and scalability
4. The Message Passing Interface
5. Parallelization strategies for numerical simulations: Loop-level parallelization, domain decomposition
6. Interfacing Python with other languages
7. Practical aspects of working with High-Performance clusters

The students will implement their own parallel simulation code in the accompanying project.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Zu erbringende Studienleistung / *Coursework*
Review/demonstration of simulation code from project

Literatur / *Literature*
A. Scopatz, K.D. Huff, "Effective Computation in Physics" (O'Reilly 2015)

Modul / *Module*

Industrial manufacturing and application of solar cells and modules / Industrielle Fertigung und Nutzung von Solarzellen und Modulen

Nummer *Number*	11LE68MO-4114		
Modulverantwortlicher *Responsible person*	Dr. Dirk Holger Neuhaus	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English *(or German)*
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	• Basic understanding of physics and chemistry • Module “Solar Energy“		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 h lecture with integrated exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90h (in class + preparation of classes)		

Lernziele / *Learning objectives*

Die Studenten bekommen einen umfassenden Einblick in die Herstellung von Solarzellen und Solarmodulen. Dabei werden neben Anlagen, Materialen und Prozessen auch Herstellungskosten, Energieverbrauch und verursachte Treibhausgasemissionen betrachtet. Anwenderrelevante Eigenschaften des Solarmodules wie Modulleistung, jährlichen Energieertrag, Modulzuverlässigkeit und Stromgestehungskosten können berechnet werden. Der Student bekommt einen Überblick über weltweite Märkte und Produktionskapazitäten sowie neu aufkommende Märkte der integrierten Photovoltaik.

The students will gain a comprehensive insight into the manufacturing process of solar cells and solar modules. In addition to equipment, materials and processes, the lecture will cover total manufacturing cost, energy consumption and generated greenhouse gas emissions. Students will be able to calculate user-relevant properties of solar modules such as module power, annual energy yield, module reliability and levelized costs of the generated electricity. The students will gain an overview of global markets and production capacities as

well as emerging markets of integrated photovoltaics.

Inhalte Vorlesung / *Content of the lecture*

- Weltweite Märkte und Produktionskapazitäten
- Herstellung von kristalline Silizium Solarzellen und Solarmodulen mit dem Fokus auf die heute dominierenden Prozesstechnologien, Anlagen und Materialien
- Verlustmechanismen in Solarmodulen (optische Gewinne, optische Verluste, Modultemperatur, elektrische Verluste)
- Material- und Energieverbrauch bei der Herstellung von Solarmodulen, Herstellungskosten sowie verursachte Treibhausgasemissionen
- Modulzuverlässigkeit und Ausfallmechanismen, Qualifizierung, Testverfahren
- Berechnung des solaren Energieertrages unter Berücksichtigung der solaren Einstrahlung, der Umgebungstemperatur, Modul- und Systemeigenschaften
- Berechnung der Stromgestehungskosten von Solarmodulen (LCOE)
- Integrierte Photovoltaik, bei der Solarzellen in Bauteile integriert werden und zusätzliche Funktionen übernehmen (Gebäude-integrierte Photovoltaik, Vehikel-integrierte Photovoltaik, …)

- *Global markets and production capacities*
- *Manufacturing of crystalline silicon solar cells and solar modules with focus on state-of-the-art production processes, equipment and materials*
- *Loss mechanisms in solar modules (optical gains, optical losses, module operation temperature, electrical losses)*
- *Material and energy consumption required for the production of solar modules, total manufacturing cost as well as generated greenhouse gas emissions*
- *Technologietrends / Technology trends*
- *Module reliability and failure mechanisms, qualification and test procedures*
- *Modelling of the solar energy yield considering the local solar insulation, the local ambient temperature as well as module and system parameters*
- *Calculation of the power generation cost of solar modules (LCOE)*
- *Integrated photovoltaics, with solar cells integrated into constructional elements that carry additional functionalities (building-integrated photovoltaics, vehicle-integrated photovoltaics, …)*

Zu erbringende Prüfungsleistung / *Course-based assessment*

Klausur / *written supervised exam*

Zu erbringende Studienleistung / *Coursework*

Zur Vertiefung der Vorlesungsinhalte werden Übungsaufgaben ausgegeben. Diese werden mit der Systemsimulationssoftware polysun zu Hause bearbeitet und in der Vorlesung besprochen. Die Studenten erhalten für die Vorlesung eine kostenfreie Lizenz für polysun.

To further improve the knowledge of the lecture the student will receive written

excrescences. The student has to solve the exercise with the system simulation software polysun at home; discussion of the exercise will take place within the lecture. The students will receive a free licence for polysun for the duration of the lecture.

Literatur / *Literature*

- D.H. Neuhaus, K.A. Münzer, Industrial Silicon Wafer Solar Cells, Advances in OptoElectronics 2007, https://www.hindawi.com/journals/aoe/2007/024521/abs/
- K.A. Münzer, Photovoltaik Technologie – Mein Berufsleben für die Photovoltaik, Berlin 2015, ISBN 978-3-86460-273-3
- A. Goetzberger, B. Voß, J. Knobloch, Sonnenenergie: Photovoltaik, Teubner, Stuttgart 1994, ISBN 3-519-03-214-7
- M.A. Green, Solar Cells, University of New South Wales, Kensington 1982, ISBN 0-85823-580-3
- M.A. Green, Silicon Solar Cells – Advanced Principles & Practice, University of New South Wales, Kensington 1995, ISBN 0-7334-0994-6
- W. Hoffmann, The Economic Competitiveness of Renewable Energy, John Wiley & Sons, New Jersey 2014, ISBN 978-1-118-23790-8
- J.A. Duffie, W.A. Beckman, Solar Engineering of Thermal Processes, 4th Edition, New Jersey 2013, John Wiley & Sons, ISBN 978-0-470-87366-3
- polysun simulation software, user manual, Vela Solaris AG, Winterthur/Switzerland 2017, https://www.velasolaris.com

Modul / *Module*

Innovation and Evolution of Technical Systems

Nummer *Number*	11LE68MO-5565		
Modulverantwortlicher *Responsible person*	Dr. Klaus Markus Hofmann	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen: *Connected events*	Seminar	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4 Seminar	**Angebotsfrequenz** *Regular cycle*	Summer term, max 25 participants
Arbeitsaufwand *Workload*	180 hours		

Lernziele / *Learning objectives*

- Systemic understanding of evolution of technological, social systems and infraculture
- Insight in innovation process, innovation-networks, eco-systems, transition process
- Awareness of technical, societal, environmental and legal influences on innovation process
- Understanding basics economics of infrastructure provisioning and emergence/role of institutions
- Ability to analyse societal patterns, economic, spatial structures and their effects on eco-systems
- Ability to identify synergies in infrastructure development, even across sectors
- Principles of open innovation, transdisciplinary cooperation and co-development with prosumers
- Overview about technological platforms for energy, communication and transport
- Sustainability indicators for infrastructure design and operation (local, regional and national level)

Inhalte Vorlesung / *Content of the lecture*

- Innovation and Innovation, Infracultural Analysis and Development Framework
- Sustainable infrastructures enable meeting societal needs to move, have access, communicate, trade and maintain relationships without sacrificing future societal or ecological requirements
- Assessment of requirements, cultural patterns and for communication and mobility infrastructure
- Aspects on innovation, digitalization, technology sociology, path dependency and human ecology
- Applied system thinking (e.g. Complex adaptive Systems, LTIS) regarding societal, environmental, cultural and economic contexts for transformation of technical

systems,
- Identifying existing and emerging patterns of communication, transport & mobility
- Concepts of commons; modern commons, dilemmas (e.g. market failure, free rider)
- Systemic approach towards platforms, programmes and application layers in infrastructure sector
- Design of sustainable business models in cooperation of actors in the private and public sector
- Impacts of digital transformation (IoT) on infrastructure systems, men, society and environment
- Cases: electrical mobility, data analytics, smart grids, IoT, and ethical boundaries

Methods/didactics:
- Oral presentation, media
- discussion, interactive Q&A
- worksheets, literature briefs
- individual & group work
- case studies presentations

Zu erbringende Prüfungsleistung / *Course-based assessment*
Individual papers + poster presentation of project results.

Zu erbringende Studienleistung / *Coursework*
Active participation; attendance and readings (tbd) are required.

Literatur / *Literature*
• tbd

Modul / *Module*

Keramische Werkstoffe der Mikrotechnik / Ceramic Materials for Microsystems

Nummer *Number*	11LE50MO-5102		
Modulverantwortlicher *Responsible person*	Prof. Dr. Thomas Hanemann	**Einrichtung** *Organisational unit*	Chair Werkstoff Process Technology, IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	German
Empfohlene Voraussetzungen *Recommended preconditions*	Kenntnisse der Werkstoffwissenschaft, z.B. Zustandsdiagramme, physikalische Eigenschaften verschiedener Materialklassen, Kristallsysteme, thermodynamische Eigenschaften und Kinetik kristalliner und nichtkristalliner Festkörper		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90 hours (28 hours full-time attendance course of study + 62 hours self-study)		

Lernziele / *Learning objectives*

Ziel des Moduls ist es, die technologischen und physikalischen Grundlagen der keramischen Werkstoffe und die zugehörigen Prozessierungsmethoden zu vermitteln. Mikrosystemtechnisch relevante Aspekte der keramischen Werkstoffe und ihrer Prozessierungsmethoden sollen aufgezeigt werden.

Inhalte Vorlesung / *Content of the lecture*

Im ersten Teil werden die allgemeinen Aspekte keramischer Werkstoffe mit den Schwerpunkten Oxid- und Nichtoxidkeramiken sowie Magnetkeramiken behandelt. Weitere Kapitel betreffen die Herstellung keramischer Pulver, die Charakterisierung von Pulvern und Keramiken und die Herstellung und Beschreibung von Pulversuspensionen. Anschließend wird die Herstellung keramischer Komponenten für die Mikrotechnik nach unterschiedlichen Verfahren (Trockenpressen, Schlickergießen, elektrophoretische Abscheidung, Foliengießen, pulverkeramisches Spritzgießen) vorgestellt. Die Lecture schließt mit einer Einführung in Sinterprozesse. Es besteht die Möglichkeit, im Anschluss an die Lecture ein ca. 2-wöchiges BlockLaboratory zu absolvieren. Dieses dient dazu die in der Lecture theoretisch behandelten Themen praktisch umzusetzen.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination.

Literatur / *Literature*
Begleitend zur Lecture wird ein Skriptum und werden Handzettel der Lecturesfolien zur Verfügung gestellt.

Modul / *Module*

Klebtechnik / Adhesive Bonding

Nummer *Number*	11LE68MO-4208		
Modulverantwortlicher *Responsible person*	Dr. Michael May	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	None		
Zwingende Voraussetzungen: *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90h		

Lernziele / *Learning objectives*

The educational objective of this course is to develop an understanding of adhesive bonding. The students will learn about the chemistry and manufacturing of adhesive joints, potential applications and the environmental impact of the use of adhesive bonding technology in relevant applications.
Additionally, the students will understand the failure behavior of adhesively bonded joints and will be able to identify appropriate experimental characterization methods. Furthermore, the the students will be able to describe adhesively bonded joints using appropriate modeling strategies.

Das primäre Lernziel dieser Veranstaltung ist, ein grundlegendes Verständnis für Klebverbindungen zu schaffen. Es werden Kenntnisse über die Chemie von Klebstoffen, die Herstellung von Klebverbindungen und, potentielle Anwendungen vorgestellt. Zudem wird der Einfluss auf die Umwelt diskutiert.
Zusätzlich werden die Kursteilnehmer das Versagen von Klebverbindungen verstehen und geeignete experimentelle Charakterisierungsmethoden auswählen können. Abschließend werden Modellierungsstrategien für die Beschreibung von Klebverbindungen vorgestellt.

Inhalte Vorlesung / *Content of the lecture*

In the field of mobility and transport, the use of novel materials and the especially clever combination of materials is the key for weight reduction, and consequently for increased energy efficiency. Adhesive bonding has shown to be a key technology to achieve these

goals.

This course covers the basics of adhesive bonding technology. Building on this, the course will impart knowledge on experimental characterization of joints as well as modeling approaches.

Topics:
• Applications of adhesive bonding
• Chemistry of adhesives
• Manufacturing of adhesive joints
• Environmental impact of adhesives
• Failure mechanisms in adhesive oints
• Characterization of adhesives joints
• Simplified and detailed modeling approaches

Im Bereich der Mobilität und des Transportwesens ist der geschickte Einsatz verschiedener Materialkombinationen ein Schlüsselfaktor für die Reduktion des Fahrzeuggewichts und folglich der Energieeffizienz. Die Klebtechnik hat sich dabei als Schlüsseltechnologie zur Erreichung dieser Ziele herausgestellt.
Diese Vorlesung beschreibt die Grundlagen der Klebtechnik. Darauf aufbauend wird in der Vorlesung Wissen über die experimentelle Charakterisierung von Klebverbindungen sowie über geeignete Modellierungsansätze vermittelt.

Themen:
• *Anwendungen von Klebverbindungen*
• *Chemie von Klebstoffen*
• *Fertigung von Klebverbindungen*
• *Auswirkungen auf die Umwelt*
• *Versagensmechanismen in Klebverbindungen*
• *Mechanische Charakterisierung von Klebverbindungen*
• *Vereinfachte und detaillierte Simulationsansätze*

Zu erbringende Prüfungsleistung / *Course-based assessment*
written or oral examination

Zu erbringende Studienleistung / *Coursework*
If any, they will be announced during the first lecture.

Literatur / *Literature*
Information will be given during the lectures.

Modul / *Module*

Konstitutive Gleichungen und Diskretisierungsverfahren zur Versagensmodellierung / Physics of Failure

Nummer *Number*	11LE68MO-5121		
Modulverantwortlicher *Responsible person*	S. Hiermaier	**Einrichtung** *Organisational unit*	Chair Nachhaltige Ingenieurssysteme
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 hours (32 hours Full-time attendance course of study + 58 hours Self-study)		

Lernziele / *Learning objectives*

With this module Students are able to distinguish between damage and failure as two distinct process types in materials as other thermo-mechanic behaviors. Basic differences between phenomenological and physics based modeling approaches become evident. Specifically, the multi-scale character of the process is recognized. The resulting dimension of related resources for computations as well as the necessity for scale-bridging methodologies is learnt. Furthermore, a variety of experimental and numerical methods for characterizing and modeling the processes is investigated.

Die Studierenden können zwischen Schädigungs- und Versagensprozessen unterscheiden und beides in das übrige thermo-mechanische Verhalten von Werkstoffen einordnen. Sie erkennen die Unterschiede zwischen phänomenologischen und physikalischen Modellierungen von Schädigungs- und Versagensprozessen. Insbesondere wird der skalenübergreifende Charakter dieser Vorgänge deutlich. Die daraus resultierenden Dimensionen im Berechnungsaufwand sowie mögliche Lösungen mit skalenüberbrückenden Methoden erschließen sich.
Daneben wird klar, dass es unterschiedlicher experimenteller und numerischer Verfahren zur Charakterisierung und Modellierung dieser Prozesse bedarf.

Inhalte Vorlesung / *Content of the lecture*

tba

Zu erbringende Prüfungsleistung / *Course-based assessment*

written or oral examination

Modul / *Module*
Kontakt, Adhäsion, Reibung / Contact, Adhesion, Friction

Nummer *Number*	11LE50MO-5252		
Modulverantwortlicher *Responsible person*	L. Pastewska	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*		**Sprache** *Language*	English or German
Zwingende Voraussetzungen *Mandatory requirements*	Knowledge of a programming language (e.g. Python, C, C++, Fortran, MATLAB)		
Empfohlene Voraussetzungen *Recommended preconditions*	Micromechanics		

Empfohlenes Fachsemester:: *Recommended term of study*	3	**ECTS-Punkte:** *ECTS credits*	6
SWS: *Semester week hours*	2 lecture + 2 exercise	**Angebotsfrequenz:** *Regular cycle*	Winter term
Arbeitsaufwand: *Workload*	180 Hours (64 full-time attendance course of study + 116 self-study)		

Lernziele / *Learning objectives*

The student
- can explain the physical origins of surface forces and the role of elastic deformation in contact;
- knows models for contact and sliding of smooth and rough interfaces in non-adhesive and adhesive limits and can explain their respective range of applicability;
- can explain the mathematical origin of the boundary element method and apply it to solve contact problems in engineering.

Inhalte Vorlesung / *Content of the lecture*

This lecture introduces models for the mechanics of smooth and rough contacts for non-adhesive and adhesive interfaces. Contact mechanical models are applied in many technological areas, from interpreting atomic-force microscopy data to designing biomimetic adhesives. Examples of these applications will be given throughout the lecture.

1. Introduction: Contact area and contact stiffness
2. Theory of the elastic half-space
3. Contact of nonadhesive spheres: Hertz's theory
4. Physical origins of surface forces
5. Contact of adhesive spheres: Johnson-Kendall-Roberts, Derjaguin-Muller-Toporov, Maugis-Dugdale
6. Surface roughness: Power spectral density, random process model

7. Contact of nonadhesive rough interfaces: Greenwood-Williamson, Persson, modern numerical results
8. Contact of adhesive rough interfaces: Fuller-Tabor, Persson, modern numerical results
9. Tangential and sliding contact: Interfacial shear strength, Cattaneo-Mindlin, Savkoor
10. Contact and sliding of viscoelastic bodies: Persson's model
11. Applications of contact models: Atomic-force microscopy, biological adhesive systems and biomimetic adhesives, failure of MEMS, leakage of seals.

The lecture is accompanied by a computer lab, where the students implement a boundary element method for the solution of contact problems. The computer lab will use the programming language Python. A short introduction into Python is part of the lab sessions.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Oral examination

Zu erbringende Studienleistung / *Coursework*
Review/demonstration of boundary element code from exercise sessions.

Literatur / *Literature*
K. L. Johnson, Contact Mechanics (Cambridge University Press, 1985) D. Maugis, Contact, Adhesion and Rupture of Elastic Solids (Springer-Verlag, 2000) J. Israelachvili, Intermolecular and Surface Forces (Academic Press, 1985)

Modul / *Module*

Kontinuumsmechanik I mit Übung / Continuum mechanics I with exercises

Nummer *Number*	11LE68MO-4302		
Modulverantwortlicher *Responsible person*	D. Helm	**Einrichtung:** *Organisational unit*	INATECH
Modultyp *Module type*	Elective module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Advanced mathematics; engineering mechanics		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	2 Lecture + 2 exercises	**Angebotsfrequenz** *Regular cycle*	Summer term (starting from 2018)
Arbeitsaufwand *Workload*	180 hours (64 hours Full-time attendance course of study + 116 hours Self-study)		

Lernziele / *Learning objectives*

The objective of the module is to master the mathematical foundations of continuum mechanics in form of tensor algebra and tensor analysis as well as the knowledge of the basic structure of continuum mechanics.
The content of the topics of the lecture will be further studied by exercises in order to train the mathematical foundations and the first applications in the field of continuum mechanics.

Inhalte Vorlesung / *Content of the lecture*

- Mathematical foundations of continuum mechanics (specialized to orthonormal base systems) consisting of tensor algebra and tensor analysis
- Introduction to the basic strucutre of continuum mechanics (kinematics, balance equations, constitutive relations).

The focus lies on the treatment of small deformations and simplified examples with reference to engineering mechanics.

Inhalte Übung / *Content of the exercises*

The content of the lecture will be further studied by exercises in order to train the mathematical foundations and the first applications in the field of continuum mechanics.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination

Literatur / *Literature*
• M. Itskov, Tensor Algebra and Tensor Analysis for Engineers, Springer, 2013

Modul / *Module*

Kontinuumsmechanik II mit Übung / Continuum mechanics II with exercises

Nummer *Number*	11LE68MO-4304		
Modulverantwortlicher *Responsible person*	D. Helm	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	• Kontinuumsmechanik I / Continuum mechanics I • Kontinuumsmechanik I mit Übung / Continuum mechanics I with exercises		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term (starting from 2018)
Arbeitsaufwand *Workload*	90 hours (32 hours Full-time attendance course of study + 58 hours Self-study)		

Lernziele / *Learning objectives*

The objective of the course is the knowledge of nonlinear continuum mechanics and its applications in solid state and fluid mechanics. The content of the topics of the lecture will be further studied by exercises in order to train the mathematical foundations and the first applications in the field of continuum mechanics.

Inhalte Vorlesung / *Content of the lecture*

- Kinematics for finite deformations: representation of motion, strain tensors etc. at large deformations, geometric linearization
- Balance relations of mechanics and thermomechanics
- Principles of mechanics: principle of D'Alembert, principle of virtual displacements
- Constitutive relations for fluids and solids (e.g. lienar-elastic fluid, finite elasticity, viscoelasticity, plasticity, viscoplasticity, heat conduction, ...)
- Extension of the mathematical foundations of tensor algebra and tensor analysis to general base systems and curved coordinates

Inhalte Übung / *Content of the exercises*

The content of the lecture will be further studied by exercises in order to train the mathematical foundations and the first applications in the field of continuum mechanics.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Literatur / *Literature*
• P. Haupt, Continuum Mechanics and Theory of Materials, Springer Verlag, 2002

Modul / *Module*

Laser Scanning for Mapping Large Structures

Nummer *Number*	11LE68MO-4205		
Modulverantwortlicher *Responsible person*	A. Reiterer	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Grundverständnis für optische Messtechnik; Grundlagen in Optik und Physik *Basic understanding of optical measurement techniques; Basics of Optics and Physics*		
Zwingende Voraussetzungen *Mandatory requirements*	Keine / *None*		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 hours		

Lernziele / *Learning objectives*

Vermittlung des Verständnisses für den Aufbau und Einsatz von Laser Scanning für die Erfassung, Dokumentation und Überwachung von Großstrukturen. Einordnung von Spezifikationen kommerziell erhältlicher Systeme und Lösungen. Vor- und Nachteile von Laser Scannern für ausgewählte Anwendungen.

The lecture provides an understanding of the design and use of laser scanning for documentation and monitoring of large structures. Classification of specifications for commercially available systems and solutions. Advantages and disadvantages of laser scanners for selected applications.

Inhalte Vorlesung / *Content of the lecture*

- Grundlagen der messtechnischen Begriffe (Genauigkeit, Präzision, Auflösung, etc.)
- Komponenten eines Laser Scanners
- Herausforderungen beim mobilen Laser Scanning
- Registrierung von Punktwolken
- Geo-Referenzierung von Punktwolken
- Projektbeispiele
- Übung: Lösung konkreter Projektbeispiele (Konzipierung von Messsystemen, Vor- und Nachteile verschiedener Ansätze)
- *Basics of measurement terminology (accuracy, precision, resolution etc.)*

- *Components of a laser scanner*
- *Challenges of mobile laser scanning*
- *Registration of point clouds*
- *Georeferencing of point clouds*
- *Project examples*
- *Exercise: Solution of concrete project examples (design of measurement systems, advantages and disadvantages of different approaches)*

Zu erbringende Prüfungsleistung / *Course-based assessment*
Oral examination

Zu erbringende Studienleistung / *Coursework*
Keine *None*

Literatur / *Literature*
Literature will be provided at the beginning of the lecture

Modul / *Module*
Lattice Gas Methoden / Lattice Gas Methods

Nummer *Number*	11LE50MO-5504a		
Modulverantwortlicher *Responsible person*	A. Greiner	**Einrichtung** *Organisational unit*	Chair Simulation
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	It is advantageous but not necessary to be familiar with the basic topics of the course "Simulation".		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	2 lecture + 2 exercises	**Angebotsfrequenz:** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	180 hours (56 hours Full-time attendance course of study + 124 hours Self-study)		

Lernziele / *Learning objectives*

Lecture:
The students will learn the basic theoretical descriptions of the Lattice Gas and of the Lattice Boltzmann method and their derivation from
kinetic theory. The students will understand the application of these two methods to the computational tasks for the simulation of fluid flow.
Practical exercises:
The students will learn to apply the Lattice Gas method as well as Lattice Boltzmann method to special problems in fluid dynamics. They
will be assigned to implement the methods into an algorithm, estimate the computational cost for a given problem, and they will learn to elaborate
the result obtained by the simulation and give a detailed interpretation of the fluid flow phenomena under investigation.

Inhalte Vorlesung / *Content of the lecture*

The lectures will cover the following topics:

- From classical mechanics to statistical mechanics
- Concepts of thermodynamics
- Formal classical transport theory
- The Boltzmann transport equation (BTE)
- Methods for solving the BTE
- Simple Lattice Gas Method
- Lattice Boltzmann Method

Inhalte Übung / *Content of the exercises*
This exercise will accompany the topics given in the course on Advanced Topics in Simulation: Lattice Gas Methods. The exercises will focus on problems to be solved with the software tool Mathematica. The students will be assigned with a project to be solved by Mathematica. To pass the exercises, students have to pass minimum 50 % of the exercises sheets.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Zu erbringende Studienleistung / Coursework
The students have to complete assessed coursework in order to be admitted to the final module exam. Coursework can include regular attendance, presentations, quizzes, written exams, exercise sheets and class minutes. The nature of the coursework is defined in the description of the exercises and at the beginning of each class.

Modul / *Module*

Leistungselektronik für die Elektromobilität / Power Electronics for E-Mobility

Nummer: *Number*	11LE68MO-4106		
Modulverantwortlicher *Responsible person*	S. Reichert	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	Power Electronic Circuits and Devices (elective module)		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand: *Workload*	90 hours (28 hours full-time attendance course of study + 62 hours self-study)		

Lernziele / *Learning objectives*

It is the aim of this module to get a fundamental understanding of power electronic circuits used in E-Mobility applications like traction inverters, bidirectional chargers and onboard energy management.
The students will learn different circuit topologies and basic control structures for power electronic circuits. The interaction between the power grid and electric vehicles will be discussed.

Inhalte Vorlesung / *Content of the lecture*

Power Electronics for E-Mobility applications:

- Conductive and inductive chargers for electric vehicles
- Traction inverters and electric motors
- DC/DC converters for onboard energy management
- Control of grid connected inverters
- E-Mobility as an instrument for a better grid integration of renewable energies

Exercises/Tutorials are included in the lecture.

Zu erbringende Prüfungsleistung / *Course-based assessment*

written or oral examination

Literatur / *Literature*
Teodorescu R., Liserre M., Rodriguez P.; Grid Converters for Photovoltaic and Wind Power Systems, Wiley-IEEE, 2011

Modul / *Module*

Leistungselektronik für Photovoltaik und Windenergie / Power Electronics for Photovoltaics and Wind Energy

Nummer *Number*	11LE68MO-4107		
Modulverantwortlicher *Responsible person*	B. Burger	**Einrichtung** *Organisational unit*	Energy Systems
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	Power Electronics Circuits and Devices (elective module)		
Empfohlene Voraussetzungen *Recommended preconditions*	Knowledge in Electrical Components (Semiconductors, Inductors, Capacitors)		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 hours (28 hours full-time attendance course of study + 62 hours self-study)		

Lernziele / *Learning objectives*

Power electronics circuits convert the DC power of PV modules to grid compatible AC power. Wind turbines produce AC power with variable frequency, which has to be converted to AC with grid frequency. The commonly used hardware topologies of power electronic converters for renewable energies are shown and explained in detail. Additional aspects like MPP-tracking, supply of reactive power, low voltage ride through (LVRT) etc. are discussed.

Inhalte Vorlesung / *Content of the lecture*

- Solar Module Integrated Electronics
- Single Phase String Inverters
- Three Phase String Inverters
- Battery Chargers and Off-Grid Inverters
- PV System Technology
- Frequency converters for Wind Energy

Zu erbringende Prüfungsleistung / *Course-based assessment*

written or oral examination

Literatur / *Literature*
Robert W. Erickson, Dragan Marksimovic: Fundamentals of Power Electronics Mohan, Undeland, Robbins: Power Electronics http://nptel.ac.in/courses/Webcourse-contents/IIT%20Kharagpur/Power%20Electronics/New_index1.html https://en.wikipedia.org/wiki/DC-to-DC_converter https://en.wikipedia.org/wiki/Power_inverter https://en.wikipedia.org/wiki/Variable-frequency_drive

Modul / *Module*

Leistungselektronik: Systeme und Konzepte / Power Electronics: Devices and Concepts

Nummer *Number*	11LE50MO-5218		
Modulverantwortlicher *Responsible person*	PD Dr. Rüdiger Quay	**Einrichtung** *Organisational unit*	IMTEK; INATECH
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	None		
Zwingende Voraussetzungen *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 hours		

Lernziele / *Learning objectives*

The students will be enabled to understand materials, concepts, functioning, and design of modern power devices, circuits, and converter systems. This includes the understanding of basic concepts of power conversion (AC theory), of passive and active semiconductor devices, high-voltage operation, converter-, and control concepts, device protection, and aspects of system and power network theory. The students will be competent to analyse and design passive and active power devices such as MOSFET, Insulated Gate Bipolar IGBT, Junction FETs (JFET), thyristors, and circuits, full converter functions, integration, and analyze full system concepts. Circuits and system concepts for power conversion, such as half and full bridges, aspects high voltage operation, and design for robustness are presented, and several examples are discussed in detail.

Inhalte Vorlesung / *Content of the lecture*

The lecture Power electronics: Devices and concepts deals with the fundamentals and concepts of power devices and circuits. It comprises three parts: fundamental power conversion-concepts with focus on DC-DC and –AC conversion, more complex power circuitry, and actual power conversion systems. At the interface of modern electronics, circuit design, and control theory, advanced analysis and characterisation techniques are introduced in order to bridge the gap from modern power conversion to the understanding of systems and network systems with all aspects of power conversion. The methodologies of power-analysis, design of circuits, complex power flow, their modelling and their

characterisation are introduced along with the demonstration of their relevance to real power-components and -systems. Typical applications include DC-DC conversion for server systems, photovoltaic power conversion, and high-voltage windcraft systems.

Inhalte Übung / *Content of the exercises*
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Zu erbringende Prüfungsleistung / *Course-based assessment*
written or oral examination

Zu erbringende Studienleistung / *Coursework*
None

Literatur / *Literature*
• J. Lutz, Halbleiter-Leistungsbauelemente (in German), Springer, Berlin-Heidelberg, 2006 • N. Mohan, Power Electronics, A first course, John Wiley and Sons, 2012 • Further literature for systems are presented during the lecture

Modul / *Module*
Life Cycle Management

Important: This course requires each participant to work on her/his own laptop with the openLCA software (http://www.openlca.org/) and the ecoinvent database installed. openLCA is freeware. A copy of the ecoinvent database will be provided at the beginning of the course.

Nummer *Number*	10LE07MO-M.64087		
Modulverantwortlicher *Responsible person*	Prof. Stefan Pauliuk	**Einrichtung** *Organisational unit*	Faculty of Environment and Natural Resources
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lectures, exercises, group work	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Calculations with Excel, Basic knowledge on vectors, matrices, matrix multiplication and matrix inversion.		
Zwingende Voraussetzungen *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	Three weeks full time of course of study (block format). Approx. 4 SWS	**Angebotsfrequenz** *Regular cycle*	Irregularly in winter, and in block format; limited places available for SSE students. **Next start date: 07.01.2019**
Arbeitsaufwand *Workload*	150h (of which 60 hours attendance)		

Lernziele / *Learning objectives*

- Basic knowledge of quantitative systems analysis of human-environment systems, basics of material and energy flow analysis.
- Detailed knowledge about the state of the art, the software, and databases of life cycle assessment according to the standards ISO 14040 and 14044.
- Basic knowledge of life cycle impact assessment methods.
- Soft skills: discussion, scientific writing skills, capacity for team work.
- At the end of the course, the successful participant will be able to conduct, interpret, document, and present life cycle assessment studies of products or technical installations using state-of-the-art tools and databases.

Inhalte Vorlesung / *Content of the lecture*

The course enables participants to conduct, interpret, document, and present life cycle

assessment studies of products or technical installations using state-of-the-art tools and databases.

During the first half of the course, the motivation behind and theory of life cycle assessment, including the modelling of life cycle inventories and life cycle impact assessment, is presented. The participants conduct exercises and study the relevant literature.

During the second half, the participants learn how to conduct and document a life cycle assessment study that meets both ISO and scientific standards. The participants form small groups of 2-3, chose a product or installation, and perform a life cycle management case study. The final report on the case study is due at the end of the module. It will be graded and the result will account for two thirds of the final grade of the course.

During the second half, background lectures and discussions on the potential, limits, applications, and future development of life cycle management will be held.

A written exam (1.5 hours), the result of which accounts for one third of the final grade, will be held at the end of the course.

The module is interactive and encourages strong student participation.

Inhalte Übung / *Content of the exercises*

See above.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written exam (33%), Term paper + group work (67%)

Zu erbringende Studienleistung / *Coursework*

None. However, the module is interactive and encourages strong student participation.

Literatur / *Literature*

- LCA Textbook: http://www.lcatextbook.com/. Much of the basic material of the course will be based on this book.
- OpenLCA tutorials (http://www.openlca.org/videos).
- Manual of the ReCiPe impact assessment method (http://www.lcia-recipe.net/file-cabinet/ReCiPe_main_report_MAY_2013.pdf

Modul / *Module*
Lightweight Design and Materials

Nummer *Number*	11LE68MO-4221		
Modulverantwortlicher *Responsible person*	Prof. Dr.-Ing. Frank Balle	**Einrichtung** *Organisational unit*	INATECH-EFM
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 Semester
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English or German
Empfohlene Voraussetzungen *Recommended preconditions*	B.Sc. Mechanical Engineering, Materials Science, Production Engineering, Materials Design		
Zwingende Voraussetzungen *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90h (28 h Präsenz + 62 h Selbststudium/Vor- und Nachbereitung)		

Lernziele / *Learning objectives*

Die Studierenden sind in der Lage:

- Auswahlkriterien für Leichtbaukonzepte zu formulieren und zu bewerten,
- Leichtbau als einen wichtigen Ansatz zur Nachhaltigkeit technischer Systeme zu erklären und weiterzuentwickeln,
- die zentralen metallischen Leichtbauwerkstoffe zu benennen und aktuelle Anwendungen incl. deren Legierungs- und Gefügevarianten zu beschreiben sowie korrespondierende Herstellverfahren und ausgewählte Weiterverarbeitungsmöglichkeiten zu erläutern,
- Einsatzmöglichkeiten und -grenzen für den metallischen Leichtbau im Vergleich zum Leichtbau mit Verbundwerkstoffen zu bewerten,
- selbstständig werkstoffspezifische Lösungsstrategien für den werkstofflichen Leichtbau zu definieren und vorzuschlagen,
- bestimmte Werkstoffkonzepte vergleichend zu bewerten und
- diese für typische Anwendungsfälle im konstruktiven Maschinenbau mit besonderem Blick auf eine nachhaltige Entwicklung technischer Systeme auszuwählen.

The students are able to:

- *to frame and evaluate selection criteria for lightweight design concepts*
- *to explain and to develop lightweight concepts as one important approach to the sustainability of technical systems based on lightweight materials*
- *to specify essential light metal alloys and current applications including their alloying and structural concepts*
- *to select corresponding manufacturing methods and further processing options*
- *to evaluate possible applications and limits for lightweight metallic concepts in comparison to an approach by composite materials*
- *to define and propose material-specific strategies for lightweight solutions*
- *to evaluate and compare certain material concepts for lightweight components*
- *to compare modern lightweight solutions with a special focus on sustainable development of engineering systems*

Inhalte Vorlesung / *Content of the lecture*

- Motivation von Leichtbaukonzepten und Ansätze für Nachhaltige Technische Systeme
- Leichtbaustrategien und Auswahlkriterien
- Metallische Leichtbauwerkstoffe: Aluminium, Titan und Magnesium und deren Legierungen
- Leichtbau mit Stählen
- Leichtbau mit polymeren Verbundwerkstoffe
- Weitere Ansätze zum werkstofflichen Leichtbau (z.B. Faser-Metall-Laminate, amorphe Metalllegierungen, metallische und keramische Verbundwerkstoffe)

- *Basics and motivation of lightweight design by materials engineering*
- *Lightweight strategies and criteria for materials selection*
- *Light alloys: Aluminium, Titanium, Magnesium and their alloys*
- *Lightweight steels*
- *Lightweight with Polymer-Matrix-Composites (PMC)*
- *Further lightweight approaches:*
  - *Fiber-Metal-Laminates (FML)*
  - *Bulk metallic glasses (BMG)*
  - *Metal- and ceramic-matrix-composites (MMC, CMC)*

Zu erbringende Prüfungsleistung / *Course-based assessment*

Mündliches Prüfungsgespräch

Oral examination

Zu erbringende Studienleistung / *Coursework*

None

Literatur / *Literature*

- B. Klein: Leichtbau-Konstruktion – Berechnungsgrundlagen und Gestaltung; 10. Auflage, Springer Vieweg, Wiesbaden, 2013
- H.E. Friedrich (Hrsg.): Leichtbau in der Fahrzeugtechnik, Springer Vieweg, Wiesbaden, 2013
- F. Henning (Hrsg.), E. Moeller (Hrsg.): Handbuch Leichtbau – Methoden, Werkstoffe, Fertigung; Carl Hanser Verlag, München, 2011
- H.P. Degischer (Hrsg.), S. Lüftl (Hrsg.): Leichtbau – Prinzipien, Werkstoffauswahl und Fertigungsvarianten; Wiley-VCH, 2009
- F. Ostermann: Anwendungstechnologie Aluminium, 3. Auflage, Springer Vieweg, Wiesbaden, 2014
- Peters, Manfred / Leyens, Christoph (Hrsg.): Titan und Titanlegierungen 3. Auflage, Wiley-VCH Verlag, Weinheim, 2002
- H. E. Friedrich, B. L. Mordike, Magnesium Technology - Metallurgy, Design Data and Applications; Springer Berlin Heidelberg, 2006
- E. Moeller, Handbuch Konstruktionswerkstoffe: Auswahl, Eigenschaften, Anwendung; Carl Hanser Verlag, 2007

Modul / *Module*

Materials Selection and Sustainable Development für Mechanical Engineering

Nummer *Number*	11LE68MO-4220		
Modulverantwortlicher *Responsible person*	Prof. Dr.-Ing. Frank Balle	**Einrichtung** *Organisational unit*	INATECH-EFM
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture + exercise	**Sprache** *Language*	English or German
Empfohlene Voraussetzungen *Recommended preconditions*	B.Sc in Mechanical Engineering, Materials Science, Production Engineering, Materials Design or similar areas		
Zwingende Voraussetzungen *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** ECTS credits	6
SWS *Semester week hours*	2 lecture + 2 exercise	**Angebotsfrequenz** Regular cycle	Winter term
Arbeitsaufwand *Workload*	180h (56 h Präsenz + 124 h Selbststudium/Vor- und Nachbereitung)		

Lernziele / *Learning objectives*

Die Studierenden sind in der Lage:

- die zentralen Werkstoffgruppen und Verarbeitungsverfahren für Ingenieuranwendungen zu benennen.
- Unterschiede zwischen diesen Werkstoffgruppen und Verarbeitungsverfahren zu erklären.
- verschiedene Kriterien der Werkstoffauswahl zu kombinieren und deren Wichtigkeit einzuschätzen.
- eine Aufgabe zur Werkstoffauswahl zu analysieren und die kennengelernten Methoden gezielt an Beispielen einzusetzen.
- konfliktäre Kriterien der Werkstoffauswahl zu beurteilen und abzuwägen.
- die getroffene Werkstoffauswahl mit einem passenden Fertigungsverfahren zu kombinieren und zu hinterfragen bzw. alternative Werkstoffe zu benennen.

The students are able:

- *to define the central material families and processing methods for engineering applications and to explain their differences*

- *to combine different criteria for materials selection and assess their importance*
- *to analyze an example for the selection of materials and to apply the methods learned by case studies*
- *to evaluate and judge conflicting criteria for materials selection*
- *to combine and to question a given materials selection in the context of a suitable development and finally to propose alternative materials*
- *to solve a self-defined case study and to review a foreign approach*

Inhalte Vorlesung / *Content of the lecture*

Die Auswahl des geeigneten Werkstoffes ist von zentraler Bedeutung für den Erfolg eines Produktes. Die Anzahl der verfügbaren Werkstoffe ist enorm und steigt stetig durch Neu- und Weiterentwicklungen verbunden mit veränderten und verbesserten Eigenschaftsprofilen. Die Werkstoffauswahl ist somit ein dynamischer Prozess, der für den Erfolg eines Produktes bzw. Unternehmens von entscheidender und nachhaltiger Bedeutung sein kann.

Es werden folgende Schwerpunkte behandelt:

- Allgemeine Aspekte der Werkstoffauswahl für nachhaltige technische Systeme
- Die wichtigsten Werkstoffgruppen und deren Eigenschaften
- Ausgewählte Methoden der Werkstoffauswahl
- Werkstoffeigenschaftsschaubilder und Materialindizes
- Konfliktäre Kriterien bei der Werkstoffentscheidung
- Geometrieeinflüsse der Werkstoffauswahl (Formfaktoren)
- Einflüsse der Einsatztemperatur
- Industriedesign und Fertigungseinflüsse
- Werkstoffauswahl im Kontext einer nachhaltigen Produktentwicklung (Eco-Audit)
- Berücksichtigung aktueller Werkstoffentwicklungen im Auswahlprozess
- Ausgewählte Übungsbeispiele (Praktische Vertiefung in den Übungen)

The selection of the right material is of central importance for the success of a product. The number of available materials is enormous and is constantly increasing due to innovations, research and development combined with changed and improved property profiles. So the selection of engineering materials is a dynamic process that can be of decisive importance for the success of a product or entire company.

Following topics will be discussed:

- *Introduction and Motivation for Materials Selection and Sustainable Engineering*
- *The Families of Engineering Materials and their Properties*
- *Selected Concepts for Materials Selection in Mechanical Design*
- *Materials Property Charts and Material Indices*
- *Multiple Constraints and Conflicting Objectives for Materials Selection*
- *Materials and their Shape*
- *Hybrid Materials and Structures*
- *Industrial Design and the World of Processes*
- *Materials and the Environment*
- *Sustainability for Engineering Applications – the Ultimate Challenge?!*
- *Corresponding Case Studies (during the exercises)*

Inhalte Übung / *Content of the exercises*

Vorlesungsbegleitende Übungsbeispiele und intensive Nutzung der Lernsoftware CES-EduPack (Granta Design, Cambridge Uk) nach Einführung in die Möglichkeiten der Software.
Die Studierenden haben die Möglichkeit eigene Beispiele und Fragestellungen einzubringen und im Rahmen der Übungen zur Diskussion zu stellen bzw. in moderierter Gruppenarbeit zu lösen.

The exercises are synchronized with the lectures. So all important aspects will be reiterated and studied by the intensive use of the learning software CES EduPack (Granta Design, Cambridge UK). The EduPack-Software is introduced in the first exercises and central tool of all exercises.
The students have also the opportunity to contribute their own examples or self-defined case studies and discuss them during the hands-on exercises or to solve them in a self-organized group, which is coached by the lecturer and his team.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Mündliches Prüfungsgespräch

Oral examination

Zu erbringende Studienleistung / *Coursework*

None

Literatur / *Literature*

- M. F. Ashby: Materials Selection in Materials Design. 5th edition, Elsevier Verlag, 2017
- M.F. Ashby, A. Wanner (Hrsg.) C. Fleck (Hrsg.): Materials Selection in Mechanical Design: Das Original mit Übersetzungshilfen. Easy-Reading-Ausgabe, 3. Aufl., Spektrum Akademischer Verlag, 2006
- M. Reuter: Methodik der Werkstoffauswahl – Der systematische Weg zum richtigen Material. Hanser Verlag, 2. Auflage, 2014
- J. M. Allwood, J. M. Cullen: Sustainable Materials – without the hot air. UIT Cambridge, 2015
- M. F. Ashby: Materials and Sustainable Development. Elsevier-BH Verlag, 2016
- M. F. Ashby: Materials and the Environment. Elsevier-BH Verlag, 2013
- K.G. Budinsky and M.K. Budinsky : Engineering Materials, Properties and Selection. 6th edition, Prentice Hall, London, UK, 1999
- M. Kutz: Handbook of Materials Selection. John Wiley & Sons, New York, USA, 2002
- M. Bonnet: Kunststoffe in der Ingenieuranwendung. Vieweg-Teubner Verlag, 2009
- H. J. Maier, T. Niendorf, R. Bürgel: Handbuch Hochtemperatur-Werkstofftechnik. Springer-Vieweg-Verlag, 2015
- J. Shackelford: Introduction to Materials Science for Engineers. Pearson Verlag, 2009

Modul / *Module*

Mechanische Eigenschaften und Degradationsmechanismen / Mechanical Properties and Degradation Mechanisms

Nummer *Number*	11LE50MO-5115		
Modulverantwortlicher *Responsible person*	Prof. Dr. C. Eberl	**Einrichtung** *Organisational unit*	Chair Mikro- und Werkstoffmechanik
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90 hours (28 hours Full-time attendance course of study + 62 hours Self-study)		

Lernziele / *Learning objectives*

The goal is to learn how materials properties can be understood and evaluated and how they impact functionality and performance of materials and micro systems. You will learn about the physical mechanisms in structural and functional materials as well as damage evolution during the applications lifetime. Based on the physical understanding you will be able to evaluate materials and microsystem designs, improve their lifetime and performance. This allows specifying materials and systems closer to their performance limit.

Inhalte Vorlesung / *Content of the lecture*

Introduction: physical mechanisms
Fundamentals in stress and strain as well as anisotropic properties
Fundamentals in mechanics of beams and membranes explained in examples
Micro- and nanostructured materials in micro systems
Small scale characterization of mechanical properties
Intrinsic stresses
Elastic and plastic behavior
Adhesion properties
Physical principles and loading conditions in functional materials for actors and sensors.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination

Literatur / *Literature*

- M. Ohring: „The Materials Science of Thin Films“, Academic Press, 1992
- L.B. Freund and S. Suresh: „Thin Film Materials“
- T.H. Courtney: „Mechanical Behaviour of Materials“, Mc-Graw-Hill, 1990
- M. Madou: Fundamentals of Microfabrication“, CRC Press 1997
- W. Menz und P. Bley: „Mikrosystemtechnik für Ingenieure“, VCH Publishers, 1993
- Chang Liu: Foundations of MEMS, Illinois ECE Series, 2006

Modul / *Module*
Methoden der Materialanalyse / Methods of Material Analysis

Nummer *Number*	11LE50MO-5126		
Modulverantwortlicher *Responsible person*	Prof. Dr. Margit Zacharias	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	None		
Zwingende Voraussetzungen *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 hours		

Lernziele / *Learning objectives*
The module gives an overview of all state of the art measurement and analysis methods for thin films and nanoscopic structures. Special emphasis will be placed on the prospects and drawbacks of each method as well as on typical limits and potential measurement artifacts. Educational objective is to enable students to find a suitable and appropriate method to measure or detect a certain material property of interest.

Inhalte Vorlesung / *Content of the lecture*
The treated measurement and analysis techniques include optical, electrical, chemical and structural methods which detect and probe material properties like morphology/shape, film thickness, crystallinity, chemical composition, trace impurities, bonding configurations, bandgap, etc. Namely methods like AFM, SEM / TEM, APT, SIMS, XPS, SE, PL, FTIR, Raman, XRD, C-V / I-V, RBS and many more will be dealt with.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Zu erbringende Studienleistung / *Coursework*
None

Literatur / *Literature*

Modul / *Module*
Mikroelektronik / Micro-electronics

Nummer *Number*	11LE50MO-7050/672		
Modulverantwortlicher *Responsible person*	Prof. Dr. Y. Manoli	**Einrichtung** *Organisational unit*	IMTEK; Fritz-Hüttinger Professur für Mikroelektronik
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	German or English
Empfohlene Voraussetzungen: *Recommended preconditions*	Basiswissen in Elektrotechnik und gute Kenntnisse in Elektronik, insbesondere in folgenden Themenbereichen: • Halbleiterdiode • Bipolar Transistor • MOS Transistor • Operationsverstärker • Einführung in die Digitaltechnik • Grundgatter & Schaltungsfamilien • Digitale elektrische Systeme • Sequentielle Schaltungen		

Empfohlenes Fachsemester *Recommended term of study*	1	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 Lecture + 2 Exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150 hours (64 hours full-time attendance course of study + 86 hours self-study)		

Lernziele / *Learning objectives*

Modulteil Mikroelektronik:
Nach Teilnahme an diesem Modul sind Studierende in der Lage, elementare analoge integrierte Schaltkreise wie Stromspiegel und Differenzverstärker zu verstehen und zu entwerfen. Die Studierenden beherrschen die physikalischen Grundlagen des MOS-Transistors und können mit diesem Wissen einfache analoge integrierte Schaltungen entwerfen. Darüber hinaus können mikroelektronische Systeme auf Block- und Transistorebene analysiert werden.

Modulteil Micro-electronics:
Having attended the module, the students will be able to understand and to design widely used basic analog integrated circuits like current mirrors and differential amplifiers. The students understand the physical principles and the use of MOS transistors in circuits and are able to build simple circuits. Furthermore, they will be able to analyze microelectronic systems on block and on transistor level.

Inhalte Vorlesung / *Content of the lecture*

This course covers the fundamentals of microelectronics for analog circuits. It starts with a review of the CMOS process and the available components. Then, current sources, single stage amplifiers and differential amplifiers are discussed in time and frequency domain. The presentation of basic circuit concepts and their enhancements is completed with an introduction into analog circuit layout and a discussion of electronic noise in circuits.
At last, applications of the presented circuits are shown, with a special focus on MEMS sensor readout.

List of contents:
1. Introduction and review of CMOS technology and available components
2. Small signal equivalent circuit
3. Current sources
4. Single stage amplifier and its frequency behaviour
5. Differential amplifiers
6. Noise in electronic circuits
7. Analog layout
8. MEMS Applications

Inhalte Übung / *Content of the exercises*

A weekly exercise is offered. Four short tests (quizzes) during the semester will be written at the beginning of the exercise class. Approximately 40 % of the maximum points have to be achieved in order to be allowed to write the final examination.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination

Zu erbringende Studienleistung / *Coursework*

The students have to complete assessed coursework in order to be admitted to the final module exam. Coursework can include regular attendance, presentations, quizzes, written exams, exercise sheets and class minutes. The nature of the coursework is defined in the description of the exercises and at the beginning of each class.

Literatur / *Literature*

- Allen, Holberg: CMOS Analog Circuit Design, Oxford University Press
- Sedra, Smith: Microelectronic Circuits, Oxford University Press
- Razavi: Design of Analog CMOS Integrated Circuits, McGraw-Hill Higher Education.

Modul / *Module*

Modellbildung und Systemidentifikation / Modelling and System Identification

Nummer *Number*	11LE50MO-2080		
Modulverantwortlicher *Responsible person*	Prof. Dr. M. Diehl	**Einrichtung** *Organisational unit*	IMTEK; Lehrstuhl Systemtheorie
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercise	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Knowledge of • Mathematics I for Engineers and Computer Scientists • Mathematics II for Engineers • Differential Equations • Systems Theory and Feedback Control		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	3 lecture + 1 exercise	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	180 hours (64 hours full-time attendance course of study + 116 hours self-study)		

Lernziele / *Learning objectives*

Aim of the module is to enable the students to create and identify models that help to describe and predict the behaviour of dynamic systems. In particular, students shall become able to use input-output measurement data in form of time series to identify unknown system parameters and to assess the validity and accuracy of the obtained models.

Inhalte Vorlesung / *Content of the lecture*

Linear and Nonlinear Least Squares, Maximum Likelihood and Bayesian Estimation, Cramer-Rao-Inequality, Recursive Estimation, Dynamic System Model Classes (Linear and Nonlinear, Continuous and Discrete Time, State Space and Input Output, White Box and Black Box Models), Application of identification methods to several case studies. The lecture course will also review necessary concepts from the three fields Statistics, Optimization, and Systems Theory, where needed.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination

Literatur / *Literature*

- Lecture manuscript
- Ljung, L. (1999). System Identification: Theory for the User. Prentice Hall
- Lecture manuscript "System Identification" by J

Modul / *Module*

Molecular Statics and Molecular Dynamics / Molekularstatik und Molekulardynamik

Nummer *Number*	11LE50MO-5255		
Modulverantwortlicher *Responsible person*	Prof. Dr. Lars Pastewska	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture + exercise	**Sprache** *Language*	English (or German)
Empfohlene Voraussetzungen *Recommended preconditions*	Dynamik, Thermodynamik oder physikalische Chemie / Dynamics of MEMS, thermodynamics or physical chemistry		
Zwingende Voraussetzungen: *Mandatory requirements*	Grundlagen in Materialwissenschaften / Basic knowledge in materials science		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	2 lecture + 2 exercises	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	180 Hours (64 full-time attendance + 116 self-study)		

Lernziele / *Learning objectives*

The student
- understands the physics of interatomic bonds, potential energy landscapes and the statistical foundations of thermodynamics
- can transfer these concepts to molecular simulations, in particular interatomic potentials, transition paths, thermostats and barostats
- can select initial conditions and interatomic potentials, run a molecular dynamics simulation and evaluate and interpret the simulation results

Inhalte Vorlesung / *Content of the lecture*

This lecture introduces atomic-scale simulation techniques with a focus on solid mechanics.

1. Materials physics
2. Interatomic potentials
3. Molecular statics and potential energy landscapes
4. Molecular dynamics
5. Classical statistical mechanics
6. Thermostats and barostats
7. Analysis and visualization

Inhalte Übung / *Content of the exercises*
The students will solve problems from materials science with a widely used molecular simulation code.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Zu erbringende Studienleistung / *Coursework*
Successful completion of >=50% of exercise sheets.

Literatur / *Literature*
Understanding Molecular Simulation: From Algorithms to Applications, Daan Frenkel and Berend Smit (Academic Press, 2001) Computer simulation of liquids, M. P. Allen and Dominic J. Tildesley (Clarendon Press, Oxford, 1996)

Modul / *Module*
MST Design Lab

Note: This module has two partial modules (I & II) and thus duration of two terms (one year). Your previous education (particularly if you did the MST Bachelor at University of Freiburg) and your language may influence which part-modules you can, must or do not need to participate in. It is therefore recommended that you contact the responsible Professors before registering for any lab.

Nummer *Number*	11LE50MO-7002-MST		
Modulverantwortlicher *Responsible person*	Prof. Dr. Peter Woias Dr. Andreas Greiner	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	**2 terms**
Zugehörige Lehrveranstaltungen *Connected events*	11LE50P-7003-1; 11LE50P-7001-1; 11LE50P-7001-2	**Sprache** *Language*	English and German
Empfohlene Voraussetzungen *Recommended preconditions*	Electronics; experience in programming microcontrollers; willingness to approach the analysis of design tasks creatively.		
Zwingende Voraussetzungen *Mandatory requirements*	Participation in the second part module “MST Design Laboratory II for Microsystems Engineers” in summer term is only for students who successfully took part in MST Design Laboratory I in winter term.		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4 Lab	**Angebotsfrequenz** *Regular cycle*	Winter term (2nd part module in summer)
Arbeitsaufwand *Workload*	180 h (60 full-time attendance course of study + 120 self-study)		

Lernziele / *Learning objectives*
Der erste Teil des Moduls, das MST Design Laboratory I vermittelt ein grundlegendes Verständnis für die Anwendung dynamischer Konzepte im Designzyklus von Mikrosystemen. Mit den erarbeiteten Methoden sind die Studierenden in der Lage die Analyse eines mechanischen Designs bezüglich dessen dynamischen Verhaltens durch zu führen. Nach Abschluss der Analyse können die Studierenden die Bewegungsgleichungen des Systems angeben, diese im weiteren Verlauf des Designzyklus' verwenden und sind in der Lage eine Designkorrektur aufgrund der Erkenntnisse vor zu nehmen.

Im zweiten Teil des Moduls, dem MST Design Laboratory II, erfolgt der praktische Aufbau und Test der Produktidee, die im MST Design Laboratory I oder im Modul "Konstruktionsmethodik" des vorherigen Bachelor-Studiengangs Mikrosystemtechnik erarbeitet wurde.

Inhalte Übung / *Content of the exercises*

MST Design Laboratory I for Microsystems Engineers 11LE50P-7003-1 (English; winter term):
In der Veranstaltung werden den Studierenden Methoden und Werkzeuge vermittelt, die für die Bearbeitung des 4-Phasenmodells

1. Produktplanung
2. Konzipierung
3. Entwurf
4. Ausarbeitung

der Produktentstehung erforderlich sind. CAD und Grundlagen der mathematischen Modellierung werden dabei allerdings nicht vermittelt.

MST Design Laboratory I für Mikrosystemtechniker 11LE50P-7001-1 (German; winter term):
In den praktischen Übungen werden Designs mikromechanischer Systeme mit Hilfe der Langrangeschen und Hamiltonschen Beschreibungen analysiert. Es werden die Methoden erlernt die Bewegungsgleichungen zu ermitteln. Dies wird auf konkrete Beispiele angewandt. Es werden veränderte Anforderungen an die Mikrostruktur in eine Veränderung des Designs und damit die Änderung des dynamischen Verhaltens überführt und somit die Abhängigkeit des Übertragungsverhaltens von den Designparametern ermittelt.

MST Design Laboratory II for Microsystems Engineers; 11LE50P-7001-2 (English; summer term; for all students (whether German or English programs)):
Die Studierenden bilden im Praktikum Projektteams mit einer Größe von typischerweise 5 Personen, idealerweise dieselben Teams, die schon im MST Design Lab I bzw. in der Lehrveranstaltung "Konstruktionsmethodik" des Bachelor-Studiengangs MST formiert wurden. Diese Teams haben als Aufgabe die praktische Realisierung der Produktideen, die in diesen Lehrveranstaltungen konzipiert wurden. Dies umfasst Elektronikdesign, Programmierung und grundlegende mechanische Arbeiten.

Zu erbringende Prüfungsleistung / *Course-based assessment*

- Präsentation der Ergebnisse / presentation of the results
- Schriftliche Ausarbeitung in Form von Protokollen / Written protocols

Zu erbringende Studienleistung / *Coursework*

If any, it will be announced during first exercise/lab.

Literatur / *Literature*
• G. Pahl, W. Beitz, Konstruktionslehre, Springer, 2013 • G. Pahl, W. Beitz, J. Feldhusen, K.-H. Grote, Engineering Design - A Systematic Approach, Springer, 2006 • James H. Williams, Fundamentals of Applied Dynamics, John Wiley & Sons, Inc.

Modul / *Module*
Nanomaterialien / Nanomaterials - Lecture

Nummer *Number*	11LE50MO-5104		
Modulverantwortlicher *Responsible person*	Prof. Dr. Zacharias, Dr. Hiller	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90 hours (28 hours full-time attendance course of study + 62 hours self-study)		

Lernziele / *Learning objectives*

Inhalte Vorlesung / *Content of the lecture*
After a short introduction on basics of bottom-up growth the lecture will summarize the state of the art knowledge in nanomaterials growth. Highly relevant examples from research will be discussed in detail developing the knowledge of material growth as well as basic understanding in selected growth techniques. The bottom-up growth will be discussed on selected examples which include: carbon nanotubes, Si nanoclusters and nanocrystals, Si nanowires, ZnO nanowires, colloidal methods for II-VI nanoclusters, nanobiological systems. The lecture will also include some basic knowledge on size effects and high resolution characterization methods. At the end methods of functionalizing nanomaterials and surfaces will be taught.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Literatur / *Literature*
Script

Modul / *Module*
Nanomaterialien / Nanomaterials - Laboratory

Nummer *Number*	11LE50P-5105		
Modulverantwortlicher *Responsible person*	Prof. Dr. Zacharias, Dr. Hiller	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	Deutsch

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Laboratory	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 hours (28 hours Full-time attendance course of study + 62 hours Self-study)		

Lernziele / *Learning objectives*

Inhalte Vorlesung / *Content of the lecture*
Fabrication of size-controlled silicon quantum dots Atomic layer deposition (ALD) of ZnO thin films Gold nanodots/lines via phase shift nanolithography ZnO nanowire growth via vapor-solid (VS) method SnO2 nanowire growth via ionic-liquid assisted vapor-liquid-solid method (VLS) Photoluminescence spectroscopy of Si and ZnO nanostructures Imaging and elemental analysis of nanostructures using scanning electron microscopy (SEM) and energy dispersive x-ray spectroscopy (EDX)

Zu erbringende Prüfungsleistung / *Course-based assessment*

Literatur / *Literature*
Script

Modul / *Module*

Netzfreie Methoden in technischen Anwendungen / Particle Methods in Engineering

Nummer *Number*	11LE68MO-5122		
Modulverantwortlicher *Responsible person*	S. Hiermaier G. Ganzenmüller	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercise	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	2 Lecture + 2 Exercises	**Angebotsfrequenz** *Regular cycle*	Summer term; max. 20 participants
Arbeitsaufwand *Workload*	180 hours (56 hours Full-time attendance course of study + 124 hours Self-study)		

Lernziele / *Learning objectives*

Netzfreie Methoden sind ein alternatives Diskretisierungsverfahren für die partiellen Differentialgleichungen der Kontinuumsmechanik. Im Vergleich zu den etablierten netzbasierten Verfahren, z.B. Finite Elemente oder Euler-CFD, besitzen netzfreie Methoden Vorteile wenn große Deformationen abgebildet werden sollen. So sind typische Einsatzgebiete für netzfreie Methoden der Automobilcrash, Meteoritenimpakt, Bird-Strike auf Flugzeuge, aber auch zerspanende Vorgänge in der Fertigung.

Lernziele:

- Verstehen der prinzipiellen Vorgehensweisen bei der Diskretisierung von gekoppelten Differentialgleichungen in Zeit und Raum.
- Erfahrung im Programmieren eines C++-Programms für dynamische Simulationen
- Verstehen von explizite Zeitintegrationsalgorithmen
- Erwerben von grundlegenden Kenntnissen der Kontinuumsmechanik und der Materialmodellierung

Meshfree Methods are alternative approaches for discretizing the partial differential equations of continuum mechanics. In comparison with the established mesh-based methods for this purpose, i.e., Finite Elements or Euler-CFD, meshfree methods offer advantages when large deformations are to be modelled. Typical applications of meshfree methods include automotive crash, meteorite impact analysis, bird-strike in aviation, and machining processes such as drilling.

Learning objectivess:

- *Understanding of the principal steps involved in discretizing coupled differential equations in space and time*
- *Acquiring practice in programming C++-code for dynamic simulations*
- *Understanding explicit methods for time integration*

- *Acquiring fundamental knowledge in continuum mechanics and numerical modelling of material behaviour.*

Inhalte Vorlesung / *Content of the lecture*

Inhalte der Vorlesung:
- Systeme von interagierenden Teilchen – Newtonsche Dynamik und Grundlagen der Moleküldynamik
- Zeitintegrationsalgorithmen
- Kontinuumsmechanik und das gekoppelte System von partiellen Differentialgleichungen, welche den Erhalt von Masse, Impuls und Energie beschreiben
- Übergang von diskreten Körpern (so wie in der Moleküldynamik) hin zu Volumenelementen, welche die Domäne beschreiben, innerhalb der die partiellen Differentialgleichungen definiert sind.
- SPH – Smooth Particle Hydrodynamics als die prototypische netzfreie Methode
- Kernelfunktionen, Näherungswerte für Felder und Divergenzen
- SPH für Festkörper und Fluide
- Gekoppelte Fluid-Festkörper Simulationen

Content of the Lecture
- *Systems of interacting particles – Newtonian Dynamics and basic Molecular Dynamics*
- *Time integration algorithms*
- *Continuum mechanics and the set of partial differential equations which describe conservation of mass, energy, and momentum*
- *Transition from discrete bodies (as in Molecular Dynamics) to volume elements which represent the domain on which the partial differential equations are defined.*
- *SPH – Smooth Particle Hydrodynamics as the prototypical meshfree method*
- *Kernel functions, field and divergence estimators*
- *SPH for fluids and solids*
- *Coupled fluid and solid simulations*

Zu erbringende Prüfungsleistung / *Course-based assessment*

As part of this module, problem sheets are provided by the lecturer in regular intervals. Solutions to these problem sheets need to be returned to the lecturer within a time span of two weeks, starting from the day the work sheet was issued. The problem sheets are marked and an individual grade is issued for each sheet. The finale grade for this module is calculated by averaging the individual problem sheet grades.

Benotung / *Grading*

The finale grade for this module is calculated by averaging the individual problem sheet grades.

Literatur / *Literature*

- William Graham Hoover, *Smooth Particle Applied Mechanics, The State of the Art*, Advanced Series in Nonlinear Dynamics: Volume 25, World Scientific Publishing, 2006

- D. C. Rapaport, *The Art of Molecular Dynamics Simulation*, Cambridge University Press, 2004
  see also: http://www.ph.biu.ac.il/~rapaport/mdbook/index.html
- Daniel V. Schroeder, *Interactive molecular dynamics*, American Journal of Physics 83, 210 (2015); doi: 10.1119/1.4901185
  see also: http://physics.weber.edu/schroeder/md/InteractiveMD.html

Modul / *Module*

Neurowissenschaften für Ingenieure / Neuroscience for Engineers

Nummer *Number*	11LE50MO-5319		
Modulverantwortlicher *Responsible person*	U. Egert	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*		**Sprache** *Language*	English or German (English if necessary; all slides and texts used are in English)
Empfohlene Voraussetzungen *Recommended preconditions*	Prior lectures on biology will be helpful but are not mandatory.		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 lecture + 1 exercise	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90 hours (42 attendance + 48 self-study)		

Lernziele / *Learning objectives*

The aim of this module is to convey an understanding of fundamental neuroscientific concepts, methods, processes and structures that define or influence the function of technical components in biomedical applications.

Inhalte Vorlesung / *Content of the lecture*

The lecture series conveys the foundations of various neuroscientific processes, structures and measuring techniques. We emphasize processes that

- influence the generation and properties of signals measurable with neuronal systems,
- influence the usability of MST components, such as sensors and implants,
- are relevant for typical fields of application of MST components, e.g. implantable sensors, prostheses, neurotechnology, etc..

In the course of the lectures we will present and overview of central neuroscientific concepts, tools and applications. Main topics are:

- Structure of the nervous systems
- Biophysics of electrical potentials
- Neuronal networks and their signals
- Sensory systems
- Foundations of learning and memory

- Interaction with neuronal networks

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Zu erbringende Studienleistung / *Coursework*
Written or oral examination

Literatur / *Literature*
Literature will be presented during the lecture

Modul / *Module*

Numerical Optimal Control in Science and Engineering

Nummer *Number*	11LE50MO-5249		
Modulverantwortlicher *Responsible person*	M. Diehl	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Project *Numerical Optimal Control in Engineering*	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Numerical Optimization (NUMOPT), Modelling and System Identification (MSI), Systems and Control Bachelor or Master lectures		
Zwingende Voraussetzungen *Mandatory requirements*	Mathematics 1 and 2 for Engineers or basic Linear Algebra and Calculus courses		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4 Lecture & Exercise	**Angebotsfrequenz** *Regular cycle*	Irregularly in winter term
Arbeitsaufwand *Workload*	180 hours		

Lernziele / *Learning objectives*

Die Studierenden verstehen wichtige in der Praxis verwendete numerische Methoden für die Lösung von Optimalsteuerungsproblemen und sind in der Lage, diese selbstständig anzuwenden.

Inhalte Vorlesung / *Content of the lecture*

- Introduction: Dynamic Systems and Optimization
- Rehearsal of Numerical Optimization
- Rehearsal of Parameter Estimation
- Discrete Time Optimal Control
- Dynamic Programming
- Continuous Time Optimal Control
- Numerical Simulation Methods
- Hamilton-Jacobi-Bellmann Equation
- Pontryagin and the Indirect Approach
- Direct Optimal Control
- Differential lgebraic Equations
- Periodic Optimal Control
- Real-Time Optimization for Model Predictive Control

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Zu erbringende Studienleistung / *Coursework*
Precondition to be admitted to the final module examination is the succesful completion of the associated exercise. Details about the exercise will be given at the start of the course and in HISINONE.

Literatur / *Literature*
• Manuscript "Numerical Optimal Control" by M. Diehl and S. Gros • Biegler, L.T., Nonlinear Programming, SIAM, 2010

Modul / *Module*
Numerical Optimal Control in Engineering - Project

Nummer *Number*	11LE50MO-5250		
Modulverantwortlicher *Responsible person*	M. Diehl	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture *Numerical Optimal Control in Science and Engineering*	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*			
Zwingende Voraussetzungen *Mandatory requirements*	Participation in the project is only possible for participants of the lecture *Numerical Optimal Control in Science and Engineering* which takes place in the same semester.		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	1	**Angebotsfrequenz** *Regular cycle*	Irregularly
Arbeitsaufwand *Workload*	90 hours		

Lernziele / *Learning objectives*

Die Studierenden sind in der Lage, numerische Methoden der optimalen Steuerung selbstständig zu programmieren, zu analysieren und anzuwenden.

Students can independently program, analyse and apply numerical methods for optimal control problems.

Inhalte Vorlesung / *Content of the lecture*

Das Projekt besteht in der Implementierung einer oder mehrerer selbstgewählter Optimalsteuerungsmethoden auf dem Computer und ihrer Anwendung auf ein oder mehrere selbstgewählte Anwendungsprobleme. Der Fokus kann eher auf Algorithmen und Performancevergleichen oder auf der Modellierung eines spezifischen Problems liegen. Resultat des Projektes ist ein dokumentierter Computer Code, ein Report, sowie eine öffentliche Präsentation.

The project work consists of a computer implementation of one ore more self-chosen optimal control methods and the application to one or more application problems. The focus could be more on the algorithmic side, e.g. on comparing different algorithm variants, or more on the modelling side, e.g. formulating and solving on interesting optimization problem. The project results are a documented computer code, a project report, and a public

presentation.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination: for details see HISinOne

Zu erbringende Studienleistung / *Coursework*
Um zur Abschlussprüfung zugelassen zu werden, muss die zu diesem Modul gehörige Lehrveranstaltung "Numerical Optimal Control in Science and Engineering" erfolgreich absolviert werden. *Successful participation in the lecture "numerical optimal control"*

Literatur / *Literature*
http://syscop.de/teaching/

Modul / *Module*
Oberflächenanalyse / Surface Analysis

Nummer *Number*	11LE50MO-5606-1		
Modulverantwortlicher *Responsible person*	Prof. Dr. J. Rühe	**Einrichtung** *Organisational unit*	IMTEK; Chair Chemie und Physik von Grenzflächen
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90 hours (28 hours Full-time attendance course of study + 62 hours Self-study)		

Lernziele / *Learning objectives*
XPS, TEM, FTIR, UPS, SEM, AFM, SPR, GIR, ATR, STM?? Got it? The performance of Sustainable Systems is often dominated by the nature of the surfaces involved. This course honours the great importance of surfaces and interfaces in Sustainable Systems engineering by introducing the most common techniques for surface analysis. Examples will be presented which are typical to various fields of Sustainable Systems engineering.

Inhalte Vorlesung / *Content of the lecture*
The techniques presented are grouped into three general topics which are imaging of surfaces (electron microscopy, scanning probe techniques), chemical analysis (XPS, SIMS, FTIR) of the composition of surfaces and methods for the determination of thicknesses (Ellipsometry, XRR, Surface Plasmon Spectroscopy) of layers. General topics from the surface sciences such as adhesion, wetting, and adsorption processes are also presented together with the techniques.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Literatur / *Literature*
Various materials are available on the website.

Modul / *Module*
Oberflächenanalyse Praktikum / Surface Analysis Lab

Nummer *Number*	11LE50P-5311		
Modulverantwortlicher *Responsible person*	Prof. Dr. J. Rühe	**Einrichtung** *Organisational unit*	Chair Chemie und Physik von Grenzflächn
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Laboratory	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90 hours (28 hours Full-time attendance course of study + 62 hours Self-study)		

Lernziele / *Learning objectives*

Bei Mikrosystemen, speziell bei solchen für die Mikrofluidik, können aufgrund des geringen Volumens Oberflächeneffekte nicht mehr vernachlässigt werden. In vielen Fällen dominieren die Eigenschaften der Oberfläche gar das Verhalten des Gesamtsystems. Ähnliches lässt sich für Bauteile sagen, die z.B. als Sensor mit biologischen Flüssigkeiten in Kontakt gebracht werden. Deshalb kommt der Oberflächenanalytik bei vielen in der Mikrosystemtechnik relevanten Fragestellungen eine zentrale Bedeutung zu. Im Praktikum sollen ausgewählte oberflächenanalytische Techniken vorgestellt und deren jeweilige Stärken und Limitierungen anhand von Beispielen aufgezeigt werden. Als Beispiele werden Fragestellungen gewählt, wie sie in den "Life Sciences" häufig auftreten.

Inhalte Vorlesung / *Content of the lecture*

Topic 1: **Determination of the layer thickness and roughness of biocompatible coatings**
Experiment 1: Using ellipsometry and x-ray reflectometry to determine the thickness of hydrogel coatings

Topic 2: **Wetting of surfaces – Surface free energies**
Experiment 2: Measurement of the contact angles of test liquids in various surfaces; Determination of the surface free energy using the Zisman method
Experiment 3: Generation and characterization of microarrays on various surfaces

Topic 3: **Proteins / peptides on surfaces**
Experiment 4: Measurement of the adsorption of blood proteins on surfaces using Surface Plasmon Resonance
Experiment 5: Characterization of the structure of protein layers using Fourier Transform Infrared Spectroscopy

Topic 4: **DNA at surfaces**
Experiment 6: Visualisation of DNA on mica using the Atomic Force Microscope

Zu erbringende Prüfungsleistung / *Course-based assessment*
Before each experiment there will be an oral examination and for each experiment the student has to submit a written laboratory report.

Literatur / *Literature*
Script

Modul / *Module*

Operations Research für Energiesysteme / Operations Research for Energy Systems

Nummer *Number*	11LE68MO-5558		
Modulverantwortlicher *Responsible person*	Prof. Dr. Anke Weidlich	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture, exercise & seminar	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	3 lecture, exercise & seminar	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150h		

Lernziele / *Learning objectives*

The students have an overview of different optimization problems in the energy sector and can choose an appropriate method for problem solving. They understand the mathematical background of linear programming, mixed-integer linear programming and other techniques that are widely applied in the energy economy. They are able to formulate mathematical models (objective functions, constraints) and are able to apply optimization methods with the help of computational tools. The students understand the background of different forecasting methods and can carry out forecasts based on time series and multiple linear regression.

Die Studierenden haben einen Überblick über verschiedene Optimierungsprobleme im Energiesektor und können eine geeignete Methode zur Problemlösung auswählen. Sie verstehen den mathematischen Hintergrund von linearer und gemischt-ganzzahliger linearer Programmierung sowie weiteren in der Energiewirtschaft verbreiteten Methoden. Sie sie sind in der Lage, mathematische Modelle (Zielfunktionen, Nebenbedingungen) zu formulieren und sie rechnergestützt zu lösen. Die Studierenden verstehen den Hintergrund verschiedener Prognosemethoden und können Prognosen basierend auf Zeitreihen und multipler linearer Regression durchführen.

Inhalte Vorlesung / *Content of the lecture*

- *Optimization problems in energy economics (e. g. unit commitment, resource scheduling)*
- *Linear and mixed-integer linear programming*
- *Dynamic programming*
- *Multi-criteria decision analysis*
- *Multiple linear regression*
- *Time series-based forecasting*

Associated exercise:
Computational tools for optimization

- Optimierungsprobleme in der Energiewirtschaft (z. B. Kraftwerkseinsatzplanung)
- Lineare und gemischt-ganzzahlige lineare Programmierung
- Dynamische Programmierung
- Multi-kriterielle Entscheidungsunterstützung
- Multiple lineare Regression
- Zeitreihenbasierte Prognosen

Associated exercise:
- Computational tools for optimization

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written documentation + written supervised examination

Zu erbringende Studienleistung / *Coursework*
Keine

Benotung / *Grading*
The module grade will be based on the written documentation (30%) and the final written supervised exam (70%).

Literatur / *Literature*

- Suhl, L., Mellouli, T.: Optimierungssysteme : Modelle, Verfahren, Software, Anwendungen. 2. Auflage, Berlin : Springer, 2009.
- Poler, R., J. Mula, M. Díaz-Madronero: Operations Research Problems: Statements and Solutions, Springer, Berlin / Heidelberg, 2014.
- Williams, H. P.: Model Building in Mathematical Programming, 5th Edition, John Wiley & Sons, 2013.

Modul / *Module*

Optical Metrology for Sustainable Production

Nummer *Number*	11LE68MO-4305		
Modulverantwortlicher *Responsible person*	Dr. Daniel Carl	**Einrichtung:** *Organisational unit*	INATECH
Modultyp *Module type*	Elective module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Knowledge about fundamental principles of refractive and diffractive optics.		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2	**Angebotsfrequenz** *Regular cycle*	Winter term (offered for the first time in Winter 2019/20)
Arbeitsaufwand *Workload*	90 h		

Lernziele / *Learning objectives*

For the majority of manufacturers, metrology plays a crucial role in quality control, being essential to avoid production of “non-good” parts and hence to stop/minimize waste of energy, materials, and productivity. In this way, optics help to make efficient use of resources and to produce high-quality parts and goods that finally really work for a long period of use. These are immediate benefits for a more sustainable world. Since here economic and environmental aspects are in line, penetration of this technology is already happening. The key is to identify the chances and to develop tailored, reliable optical metrology to do this job.
Within this context, the lecture gives insight into the fundamental principles and methods of optical metrology for production control.
In detail, students will study:

- Basic principles of geometrical optical measurements;
- Fundamentals of wave optics;
- Operation of optical sensors;
- Principles of digital data/image processing;
- Different optical measurement methods and their applications;
- Schematics to identify opportunities to improve the efficiency of production processes by optical metrology.

Inhalte Vorlesung / *Content of the lecture*

- Basic principles of geometrical optical measurements
- Fundamentals of wave optics
- Optical sensors
- Overview of optical measurement principles and their applications
- Incoherent methods (triangulation, fringe projection, …)
- Coherent methods (interferometry, speckle, holography, …)
- Confocal methods
- Examples for successful implementation of optical metrology in industry, with economical and sustainability win-win situations

The lecture includes an excursion to production control laboratories at Fraunhofer IPM.

Zu erbringende Studienleistung / *Coursework*
None

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written supervised exam.

Literatur / *Literature*
Literature will be provided at the beginning of the lecture.

Modul / *Module*

Optische Eigenschaften von Mikro- und Nanostrukturen / Optical Properties of Micro and Nano Structures - Vorlesung

Nummer *Number*	11LE50MO-5211		
Modulverantwortlicher *Responsible person*	PD Dr. Gombert, Andreas	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 Term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Term week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90 hours (32 Full-time attendance course of study + 58 Self-study)		

Lernziele / *Learning objectives*

Inhalte Vorlesung / *Content of the lecture*

Micro and nano structures have optical properties that differ from macroscopic bodies. The interaction between incident light or more generally incident electromagnetic radiation may lead to a modification of the propagation direction, the polarisation, and the spectral signature of absorption, reflection or transmission. In micro systems or similar technologies these phenonema can be used on purpose or need to be considered when manufacturing micro and nano structures. In this lecture we will work on the theoretical fundamentals as well as on selected applications.

Topics:

- Calculating with complex amplitudes
- Energy transfer at boundaries
- Two beam interference
- Huygens´ principle
- Fresnel´s zone construction
- Introduction into Fourier optics
- Kirchhoff-Fresnel diffraction integral
- Fresnel diffraction
- Fraunhofer diffraction

- Introduction into diffraction gratings
- Spectroscopic gratings
- Theory and applications of subwavelength gratings
- Photonic crystals
- Resonant structures in metalsProduction technologies for micro structures with optical functions

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination

Literatur / *Literature*

- M. Klein, T. Furtak: Optics, Springer-Verlag 1988
- E. Hecht: Optics, Addison-Wesley, 1989
- J. W. Goodman, Introduction to Fourier Optics, Mc Graw-Hill 1988.

Modul / *Module*
Pape it lab: make (bio)analytical devices out of paper!

Nummer *Number*	11LE50MO-5260		
Modulverantwortlicher *Responsible person*	Dr. Can Dincer (Lecturer) Prof. Dr. Gerald Urban	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and lab	**Sprache** *Language*	English
Empfohlene Voraussetzungen: *Recommended preconditions*	None		
Zwingende Voraussetzungen *Mandatory requirements*	Simultaneous participation in the lecture "Disposable sensors"		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lab	**Angebotsfrequenz** *Regular cycle*	Summer term; Maximum number of participants: 9
Arbeitsaufwand *Workload*	90h		

Lernziele / *Learning objectives*

- You know the fabrication techniques for paper based (bio)analytical devices.
- You overview different application fields of paper based systems.
- You learn in-depth the operation principle of some significant examples.
- You create your own design concept.
- - You develop a (bio)analytical device out of paper.

Inhalte Vorlesung / *Content of the lecture*

See lecture "Disposable sensors"

Inhalte Praktikum / *Content of the lab*

Although the development of paper lies nearly 2,000 years behind, it has been still widely used in analytical applications. Especially for on-site testing in resource-limited settings, for example in the developing world, in doctor's practice, or directly at home, there is a great and urgent need for cheap and easy-to-use (bio)analytical devices. In this sense, paper provides an attractive solution, since it offers many advantages, including a high-level manipulation of fluids in combination with a facile, low-cost, and rapid fabrication. In this lab

course, students will, in groups, design and develop (bio)analytical devices out of paper to meet the emerging needs of on-site applications.

In the first part, the participants become more familiar with the fundamentals and application areas of paper based (bio)analytical devices and learn in detail the working principle of some important examples. Eventually, each group will find an idea for its own paper based device and create a design concept.

In the second part of the course, the students learn how to design and develop paper based (bio)analytical devices in order to realize their own concept.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written examination

Zu erbringende Studienleistung / *Coursework*
A final presentation with a summary report

Literatur / *Literature*

Modul / *Module*
Partikelsimulationsmethoden / Particle Simulation Methods

Nummer *Number*	11LE50MO-5505a		
Modulverantwortlicher *Responsible person*	A. Greiner	**Einrichtung** *Organisational unit*	IMTEK; Chair Simulation
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	2 lecture + 2 exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	180 hours (64 hours Full-time attendance course of study + 116 hours Self-study)		

Lernziele / *Learning objectives*

Lecture:
The students will learn about alternative approaches to the simulation of hydrodynamic phenomena relevant for Sustainable Systems engineering. They will have a basic understanding of Molecular Dynamics, Dissipative Particle Dynamics and Smoothed Particle Hydrodynamics. They will understand the relation to continuum methods for fluid dynamics. The students will acquire the knowledge on how to apply particle methods to specific problems in microfluidics simulation.

Practical exercises:
The will be able to compile an adequate model for the description of the phenomenon under investigation. They will be able to decide which of the the respective particle methods detailed in the lecture to apply for the solution. The students will understand the meaning of particle simulation methods as an experimental tool to investigate materials behaviour through the usage of a particle simulation program and the solution of modeling and simulation assigment.

Inhalte Vorlesung / *Content of the lecture*

The lecture will cover the following topics:

- From classical mechanics to statistical mechanics
- Concepts of thermodynamics
- Molecular Dynamics (MD): Basics
- MD: Numerical Techniques
- Dissipative Particle Dynamics (DPD)
- Smothed Particle Hydrodynamics
- Energy conserving DPD
- Degrees of freedom internal to dissipative particles

Inhalte Übung / *Content of the exercises*
These exercises will accompany the topics given in the course on Advanced Topics in Simulation: Particle Methods. The exercises will focus on problems to be solved with the software tool SYMPLER, developed at IMTEK Simulation. SYMPLER is a software package published under the GPL (see http:sympler.org). It XML input language and provides a wide range of tools for the analysis of results. Direct graphical output can be followed on the computer screen. An interface to Paraview is included to observe different states of the simulation and to produce videos from the results. The students will be assigned with a project to be solved by SYMPLER. To this end, a detailed introduction on the usage of SYMPLER will be given. To pass the exercises, students have to pass minimum 50 % of the exercises sheets.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Zu erbringende Studienleistung / *Coursework*
The students have to complete assessed coursework in order to be admitted to the final module exam. Coursework can include regular attendance, presentations, quizzes, written exams, exercise sheets and class minutes. The nature of the coursework is defined in the description of the exercises and at the beginning of each class.

Literatur / *Literature*
• J. M. Haile, Molecular dynamics simulation: elementary methods, Wiley (1997) • D. C. Rapaport, The art of molecular dynamics simulation, Cambridge Univ. Press (2004) • Andrew R. Leach, Molecular modelling: principles and applications, Prentice Hall (2001) • sympler.org

Modul / *Module*
Photovoltaic Energy Conversion / Photovoltaische Energiekonversion

Nummer *Number*	07LE33MO-PHOTOVOLT		
Modulverantwortlicher *Responsible person*	Dr. Uli Würfel	**Einrichtung** *Organisational unit*	Physikalisches Institut
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercise	**Sprache** *Language*	English or German
Empfohlene Voraussetzungen *Recommended preconditions*	Knowledge of semiconductor or solid state physics advantageous		
Zwingende Voraussetzungen: *Mandatory requirements*	None		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 Lecture + 1 exercise	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*			

Lernziele / *Learning objectives*

Inhalte Vorlesung / *Content of the lecture*
• Basic structure of solar cells • Thermodynamic limit for the conversion of sunlight into electrical energy • Semiconductors: density of states, Fermi energy, doping • Generation and recombination, quasi Fermi energies • Transport of charge carriers • The pn-junction • Charge carrier selectivity • Ideal solar cells • Real solar cells: crystalline Si solar cells • Thin film solar cells • Tandem and multijunction solar cells, • Dye, organic and perovskite solar cells

Inhalte Übung / *Content of the exercises*

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Zu erbringende Studienleistung / *Coursework*
None

Literatur / *Literature*
• P. Würfel, U. Würfel, Physics of Solar Cells, Wiley-VCH, 3rd Edition 2016 • M.A. Green, Solar Cells, University of New South Wales 1982

Modul / *Module*

Photovoltaik-Praktikum / Photovoltaic Laboratory

Nummer *Number*	11LE68MO-4108		
Modulverantwortlicher *Responsible person*	Prof. Dr. Stefan Glunz, Dr. Nico Tucher	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Exercise	**Sprache** *Language*	English
Voraussetzungen zwingend *Preconditions mandatory*	Mandatory module “solar energy”		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	5 (6 ECTS as of Summer term 2018)
SWS *Semester week hours*	3	**Angebotsfrequenz** *Regular cycle*	Each term; max. 20 participants
Arbeitsaufwand *Workload*	150 hours (35h attendance + 115h preparation and self-study)		

Lernziele / *Learning objectives*

The Photovoltaic Laboratory provides an opportunity for hands-on experience with the PV-related topics introduced in the Solar Energy course. Students will get to know solar cells from a practical view and gain experience in interconnection and operation of solar cells, including evaluation of their performance. Students will understand the electrical properties of solar cells e.g. the IV-curve and related parameters; they will experience the influence of environmental conditions such as temperature, intensity of the incoming light and the angle of incidence. The examination of solar cells as a component part in electrical circuits will enable students to solve typical problems, e.g. how to connect a couple of single cells reasonably to build up a module or how to avoid problems caused by shading. Knowledge about the behavior and performance on load when used as power source is very important for the application of solar cells. Off-Grid systems will also be investigated as a practical application scenario for photovoltaic. This will bring students in contact with electrical components such as load-regulators, storage etc. These are elementary topics for solid knowledge of solar cells and crucial for ongoing research of a more application-oriented use of solar cells.

Inhalte Vorlesung / *Content of the lecture*

A broad variety of laboratory experiments will address the operating characteristics of solar cells and photovoltaic modules. Different experiments will be performed each week. These experiments include:

- Fundamental electric basics: series and parallel connection of solar cells
- Geometrical aspects and environmental conditions: Illumination, angle of incidence and

temperature dependence of the solar cell power
- Solar cell characterization: IV-curve in the dark and under illumination, maximum power point and fill factor
- Building up PV modules: I-V-characteristics of different solar modules and partial shading
- Working principle of mpp-tracking: DC/DC inverter
- Solar cells as power supply: on-load power and internal resistance
- Components and operation of a solar off-grid system
- Comparison and operation of different charge controllers: shunt-, series- and PWM regulator
- Discharge protection and DC/AC inverter

Zu erbringende Prüfungsleistung / *Course-based assessment*

- Presentation of experimental results

Zu erbringende Studienleistung / *Coursework*

- Students need to attend all laboratory sessions and need to write protocols of performed laboratory experiments

Literatur / *Literature*

- Smets, Solar Energy, UIT Cambridge 2016
- P. Würfel, Physik der Solarzelle, Spektrum - Akademischer Verlag 2000
- A. Goetzberger, B. Voß und J. Knobloch, Sonnenenergie: Photovoltaik, Teubner 1997
- M.A. Green, Solar Cells, University of New South Wales 1982
- K. Mertens, Photovoltaik, Hanser 2011
- J. Nelson, The physics of solar cells, Imperial College Press 2008

Modul / *Module*

Projektmanagement für Ingenieure / Project management for engineers

Nummer *Number*	11LE50MO-5803		
Modulverantwortlicher *Responsible person*	Prof. Dr. U. Wallrabe	**Einrichtung** *Organisational unit*	IMTEK; Chair Microactuators
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Seminar	**Sprache** *Language*	English and German (alternating)

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Seminar	**Angebotsfrequenz** *Regular cycle*	Each term (alternating language)
Arbeitsaufwand *Workload*	90 hours (28 or 32 hours Full-time attendance course of study + 58 or 62 hours Self-study)		

Lernziele / *Learning objectives*

Students shall learn the basic ideas and techniques of project management and apply them to representative examples. They shall realize that planning tasks isn't always as clear-cut as in engineer courses. A project can be structured in different ways. One plan isn't necessarily better than the other. Instead, one approach might be more practical or provide a better overview than another. Additionally, the students shall gain insight into the soft skills of project management, i.e. how to deal with operating persons, namely the project team as a social system.

Inhalte Seminar / *Content of the seminar*
The course comprises a mixture of lecture and group work with short presentations of the obtained project plans. The different phases of a project and its respective project management, i.e. project assignment, planning, execution and completion of a project, is presented as an introduction into the field. The different roles of people coping with the project, i.e. initiator or customer, project manager and staff, and their duties are presented, and their responsibilities analysed. Various planning techniques and plans will be introduced: project environment analysis, risk analysis, work breakdown structure, Gantt chart and SWOT analysis. The financial budgeting of a project will be shown: existing cost factors, their estimation and what exactly has to be considered. In addition, the more technical aspect of project planning will be supplemented with soft skills, like how to lead a discussion, mediation, etc. MS Project will be used to make the project management simpler. With its help project plans for fictitious projects will be developed. The presented lecture content will be visualized with two fictitious projects. The students will have to implement the learning matter in individual and team work. The projects are a journey round the world with fellow students after graduation and a virtual Master thesis.

Zu erbringende Studienleistung / *Coursework*
Written examination

Literatur / *Literature*
Regularly updated lecture notes are available.

Modul / *Module*
Python for Energy System and Sustainability Analysis

Nummer *Number*	11LE68MO-6002		
Modulverantwortlicher *Responsible person*	Prof. Dr. Anke Weidlich, Jan-Frederick Unnewehr, Ramiz Qussous	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Computer lab and lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Control and Integration of Grids		
Zwingende Voraussetzungen *Mandatory requirements*	Attendance during the first lecture is obligatory for those who want to keep their seat.		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4 computer lab + integrated lectures	**Angebotsfrequenz** *Regular cycle*	Summer term (max. 20 places available)
Arbeitsaufwand *Workload*	180 h (45 h in class, 60 class preparation, 75 project)		

Lernziele / *Learning objectives*

The students

- Can apply basic techniques for solving mathematical problems with Python
- Understand engineering problems described in flowcharts, and can translate flowchart descriptions into a computer program
- Can apply Python to solving mathematical problems in different scientific fields, especially in the energy and sustainability domain
- Can analyse energy system models implemented in Python
- Can create an appropriate model for approaching a research question in the energy or sustainability field and implement it in Python

Inhalte Vorlesung / *Content of the lecture*

- General introduction to Python, integrated development environment
- Fundamentals (data types, expressions, conditional execution, iterations, functions, files, matrix operations)
- Introduction to numerical methods (e. g. numerical differentiation, integration, fixed-point iteration, differential equations)
- Algorithms (flowcharts, pseudocode, complexity and runtime estimation)

- Modelling techniques and application examples from energy systems and sustainability analysis (power flow analysis, merit order models, simulations, system dynamics and others)
- Relevant data sources for the energy sector
- Data evaluation (data import and export, plotting results)

Zu erbringende Prüfungsleistung / *Course-based assessment*

Project and presentation – students choose an own research challenge, decide on a model for addressing the challenge, implement it in Python, execute it with appropriate input data, plot and interpret results, and describe the project in a report. They present their project in the class.

Zu erbringende Studienleistung / *Coursework*

Implementation assignments

Literatur / *Literature*

- Literature will be announced in the lecture
- Starting book: A. Sweigart, Automate the Boring Stuff with Python: Practical Programming for Total Beginners, No Starch Press (2015)

Modul / *Module*
Resilienzquantifizierung / Quantification of Resilience

Nummer *Number*	11LE68MO-4110		
Modulverantwortlicher *Responsible person*	I. Häring	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture with embedded exercises	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	• Basic Knowledge in any of the following domains would be of avail without being mandatory: system modeling and simulation, failure modelling, statistics, probability theory, stochastic processes, engineering models for the determination of system behavior in case of adverse, damage or disruptive loads or events, supply network modeling, critical infrastructure models, graph and network models, discrete models, coupled physical models, modeling and simulation of cyber-physical and socio-technical systems.		

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 h (32 h attendance, 58 h self-study)		

Lernziele / *Learning objectives*

Main learning targets incluce:
1. Know objectives, options and opportunities of resilience quantification for (socio) technical systems
2. Gain overview on currently used methods for informed selection and combination
3. Know methods and their main (traditional) application areas
4. Be capable to apply and tailor methods for resilience quantification

Inhalte Vorlesung / *Content of the lecture*

Main contents comprise:
1. Context, basic definitions, objectives and options of resilience quantification: resilience management process, resilience quantification and development process
2. Overview of methods for resilience quantification of socio technical cyber physical systems: resilience dimensions, resilience method taxonomy
3. Qualitative and semi-quantitative resilience assessments: ontologies, schemes and evaluation
4. Graphical and semi-formal approaches: heuristics vs. models
5. Resilience dimensional order expansions and resulting quantification bounds
6. Application of classical system analysis approaches, e.g. deterministic flux-based approaches, Markov models, stochastic processes

7. Graph-based and topological approaches: system definition, identification of disruption vector, response and recovery determination and response strategy optimization
8. Resilience quantification based on event propagation through resilience analysis layers using resilience transition matrix elements and related statistical-empirical, probabilistic, engineering and physical-simulative methods: inductive and deductive propagation
9. Input-output models, operability models: discrete and continuous
10. Coupled agent-supported engineering grid-model approaches for overall system modelling, simulation and resilience determination, in particular also for modeling of operators, citizens as well as organizational, policy and framing influences
11. Combinations of resilience quantification approaches and optimization problems in resilience engineering
12. For all resilience quantification approaches: model assumptions, application domains and examples, typical input and output data
13. Standards, emerging standards and ongoing standardization efforts

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written supervised examination

Literatur / *Literature*

- Vulnerable systems, Wolfgang Kröger and Enrico Zio, Springer, 2011
- Catalogue of risks: natural, technical, social and health risks, Dirk Proske, Springer, 2008
- Resilience engineering: models and analysis, Nii O. Attoh-Okine, Cambridge University Press, 2016
- Urban resilience for emergency response and recovery: fundamental concepts and applications, Gian Paolo Cimellaro, Springer, 2016
- Risk assessment and decision analysis with Bayesian networks, Norman Fenton and Martin Neil, CRC Press, 2013
- Risk analysis and management: engineering resilience, Ivo Häring, Springer 2015
- Principles of cyber-physical systems, Rajeev Alur, MIT Press, 2015
- Cyber-physical systems: from theory to practice, Danda B. Rawat, Joel J.P.C. Rodrigues, and Ivan Stojmenovic (eds.), CRC Press, 2016
- Cyber-physical systems: integrated computing and engineering design, Fei Hu, CRC Press, 2013
- Agent-based modelling of socio-technical systems, Koen H. van Dam, Igor Nikolic and Zoifia Lukszo (eds.), 2012, Springer
- Introduction to agent-based modeling, Uri Wilenski, Springer, 2015

Additional information:

http://www.leistungszentrum-nachhaltigkeit.de/themen/resilience-engineering/
http://www.academy.fraunhofer.de/de/weiterbildung/energie-nachhaltigkeit/resilience-engineering.html
http://www.lrfoundation.org.uk/publications/resilience-engineering.aspx
http://www.lr.org/en/news-and-insight/news/lrf-res-eng.aspx
http://frs.ethz.ch/
https://www.irgc.org/irgc-resource-guide-on-resilience/
http://link.springer.com/article/10.1007/s41125-015-0001-x
http://www.din.de/de/; http://www.iso.org/iso/home.html; http://www.iec.ch/; https://ansi.org/
Suche nach / searched for “resilience”

Modul / *Module*

RF- und Mikrowellen Bauelemente und Schaltungen / RF- and Microwave Devices and Circuits

Nummer *Number*	11LE50MO-5215		
Modulverantwortlicher *Responsible person*	R. Quay	**Einrichtung** *Organisational unit*	IMTEK;
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	5	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 hours (28 hours Full-time attendance course of study + 62 hours Self-study)		

Lernziele / *Learning objectives*

The students will be enabled to understand concepts, devices, design, and functioning of modern RF- and microwave transceiver subsystems. This includes the understanding of basic RF-concepts, passive and active devices, circuits, functionalities, their critical figures-of-merrit, and the inclusion into modules. The students will be competent to analyse passive and active RF-structures and circuits, which are relevant for any system with an RF-functionality. The competence includes the full understanding of a transmit/receive module needed for today's communcation and sensing.

Inhalte Vorlesung / *Content of the lecture*

The lecture RF- and Microwave Devices and Circuits deals with the fundamentals of RF-devices and circuits. It comprises three parts: high-frequency/RF concepts and passive structures, active electronic RF-devices, and RF-circuits and modules. At the interface of modern electronics, dielectric wave propagation, circuit design, and advanced communication and sensing, advanced analysis and characterisation techniques are introduced in order to bridge the gap from modern electronics and modern passive RF-technology to the understanding of RF-communication and sensing systems. The methodologies of RF-analysis, design of devices and circuits, and their basic figures-of-merit, their modelling and characterisation are introduced along with the demonstration of their relevance to modern RF- components and Sustainable Systems. This also includes a discussion of the underlying technology and many examples supported by RF-design tools from the microwave oven to today's RF-applications in mobile communication in the iPod.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination

Literatur / *Literature*
RF- and Microwave passives • Zinke/Brunswig, Hochfrequenztechnik, Band 1, Springer, 1999 RF-Devices • U.K. Mishra, J. Singh, Semiconductor Device Physics And Design, Springer, 2007

Modul / *Module*

RF- und Mikrowellen Design Kurs / RF- and Microwave Design Course

Nummer *Number*	11LE50MO-5244		
Modulverantwortlicher *Responsible person*	R. Quay	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Laboratory	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory preconditions*	The prior or parallel participation in either module "RF- and microwave devices and circuits" or "RF- and microwave circuits and systems" is required. No prior knowledge of the software is required.		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 laboratory	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	90 hours (28 hours Full-time attendance course of study + 62 hours Self-study)		

Lernziele / *Learning objectives*

The students will be enabled to understand, design and layout modern RF- and microwave components and systems by means of the electronic design environment Agilent Advanced Design System including the two- and three-dimensional electromagnetic simulators Momentum and EMPro 3D. The detailed use of a complex RF-software environment is a dedicated target of this course. This includes the numerical analysis of complex passive and active devices, the design and layout of hybrid and integrated circuits, and their packaging and signal flow. The students will be competent to design and layout passive and active RF-structures including packages and interconnects and circuits of relevance to everydays communication and sensing. The competence includes in-depth understanding and treatment of complex microwave systems and of general system design including the treatment of complex modulated signal flows.

Inhalte Praktikum / *Content of the laboratory*

The Design Course: RF- and Microwave Systems deals with the analysis and creation of RF-devices, circuits and systems. It comprises three aspects: the detailed electromagnetic design of high-frequency/RF passive and active structures, the modelling and layout and verification of active electronic RF-devices in circuit environments based on various semiconductor technologies, and the high-level combination of more complex microwave systems. This includes the simulation of printed circuit boards, of integrated circuits and of devices in package including RF-interconnects, and of behavioural system simulation. Advanced analysis of RF-problems, characterisation, modelling and linear and nonlinear

simulation techniques are introduced in order to combine knowledge from modern electronics (from various technologies such as silicon complementary MOS and GaAs), from component analysis, RF-circuit design principles, and system engineering. The examples include simple printed circuits boards, integrated circuits, advanced communication transceivers in mobile communication based on UMTS and LTE and modern radar.

Zu erbringende Prüfungsleistung / *Course-based assessment*
written or oral examination

Literatur / *Literature*
ADS Agilent Design System User Manual 2013 www.agilent.com search: ADS Skript: Design Course: RF- and Microwave Systems, R. Quay, 2014 (will be provided at the beginning of the lecture)

Modul / *Module*

Solarzellcharakterisierung: Vom Rohmaterial bis zur Zelleffizienz / Characterization of solar cells: From feedstock quality to final cell efficiency

Nummer *Number*	11LE68MO-4104-ab042019 (!)		
Modulverantwortlicher *Responsible person*	Dr. Martin Schubert, Dr. Tim Niewelt	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and seminar	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Module “Solar Energy”		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	180 hours		

Lernziele / *Learning objectives*

It is the aim of this module to get solid insight into characterization techniques for solar materials and solar cells with a strong focus on silicon technology. The module addresses both industrially used and lab-scale characterization methods in order to provide a solid background in loss analysis possibilities for solar cells.
This course is ideal to learn about typical real-life limitations of silicon material quality and silicon based solar cells and a very useful basis for anybody interested in the application, fabrication and improvement of solar cells.
The presentation of complex topics / scientific studies to a qualified audience will be discussed and practiced in the seminar of this module.

Inhalte Vorlesung / *Content of the lecture*

State-of-the-art measurement techniques for
- silicon material analysis: feedstock, blocks, wafers, cells
- cell characterization: local and global loss analyses
- identification of efficiency losses
- quantification of efficiency limitations
- lab-scale in-depth analyses
- industrial application
- approaches for non-silicon cells

Inhalte Seminar / *Content of the seminar*
The seminar is intended to allow for a deepened understanding of the application of characterization methods in photovoltaic research. Each student chooses an aspect / a method from the lecture contents and prepares a presentation on a recent scientific application for the fellow students. The seminar includes an introduction to means and methods for the preparation and realisation of such presentations. Furthermore, the seminar includes hands-on training in the simulation of solar cell structures and its application to optimization and problem solving in solar cell production.

Zu erbringende Studienleistung / *Coursework*
Oral presentation; attendance during the seminar (85%)

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written supervised exam or oral exam.

Literatur / *Literature*
• Schroder, Dieter K. Semiconductor material and device characterization. John Wiley & Sons, 2006. • Würfel, Peter, and Uli Würfel. Physics of solar cells: from basic principles to advanced concepts. John Wiley & Sons, 2009.

Modul / *Module*
Sicherheit und Privatheit in der Informationsgesellschaft / Security and Privacy in the Information Society

Nummer *Number*	11LE68MO-4401		
Modulverantwortlicher *Responsible person*	N.N.	**Einrichtung** *Organisational unit*	INATECH; Chair for Security and Privacy
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*		**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 seminar	**Angebotsfrequenz** *Regular cycle*	Currently not available; Reappointment of Chair in preparation
Arbeitsaufwand *Workload*	150 hours (56 hours full-time attendance course of study + 94 hours self-study)		

Lernziele / *Learning objectives*
Goal of the module *Security and Privacy in the Information Society* is to give participants insights into the research areas Security in Energy, Big Data and in Business Process Management and Internet Privacy. Additionally, the module aims at giving the opportunity to practice the systematic analysis of scientific texts.

Inhalte Seminar / *Content of the seminar*
tba

Zu erbringende Prüfungsleistung / *Course-based assessment*
tba

Modul / *Module*

Sicherheit und Privatheit in resilienten Systemen / Security and Privacy in Resilient Systems

Nummer *Number*	11LE68MO-9030		
Modulverantwortlicher *Responsible person*	Prof. Dr. D. Engel	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen: *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Students will need a Laptop with Microphone and ideally camera.		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 lectures + 2 exercises	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	150 hours (56 hours full-time attendance course of study + 94 hours self-study)		

Lernziele / *Learning objectives*

Students should learn the basics of cryptology and their application in cryptographic protocols. Students will get to know current cyber security threats, countermeasures and their limitations. Furthermore, the issue of privacy protection in light of EU GDPR is discussed, also in its relation to security strategies, the goals of which are sometimes in opposition with privacy protection. The limits of technical concepts and models which enable privacy protection and how they differ from the security viewpoint will be reviewed. The lecture will handle security vs. privacy as well as the application of privacy enhancing and transparency enhancing techniques. Additionally the "right to be forgotten" will be discussed.

Inhalte Vorlesung / *Content of the lecture*

Topics discussed are:

- Basics of cryptology
- Current threats
- Security measures
- Privacy vs. security
- Privacy and transparency enhancing mechanisms
- Privacy engineering & assessment
- Security in the context of business processes and in complex systems

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination, exercises and volunteer presentations

Literatur / *Literature*
• Stallings, W. “Cryptography and Network Security: Principles and Practice”, 7th edition, Pearson, 2016. • Bishop, M. “Computer Security: Art and Science”, 2nd edition, Addison Wesley, 2017. • Troncoso, C., Danezis, G., Isaakidis, M., and Halpin, H. “Systematizing Decentralization and Privacy: Lessons from 15 years of research and deployments”, PoPETs 2017 (4):307–329, 2017. Available online: https://petsymposium.org/2017/papers/issue4/paper87-2017-4-source.pdf. • Wicker, S. “Cellular Convergence and the Death of Privacy”, Oxford University Press, 2013. • Schneier, B. “Click Here to Kill Everybody: Security and Survival in a Hyper-connected World”, Norton & Company, 2018. • Cavoukian, A. “Privacy by Design in Law, Policy and Practics”, Information and Privacy Commission Canada, 2011. Available online: http://www.ontla.on.ca/library/repository/mon/25008/312239.pdf.

Modul / *Module*

Strukturelle Robustheit: Resiliente Entwurfsprinzipien / Structural Robustness: Resilient Designs

Nummer *Number*	11LE68MO-4109		
Modulverantwortlicher *Responsible person*	Dr. A. Stolz	**Einrichtung** *Organisational unit*	INATECH; external lecturer
Modultyp *Module Type*	Elective module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercise	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	SSE Modul Fundamentals of resilience SSE Modul Design of large urban infrastructures		

Empfohlenes Fachsemester:: *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	3
SWS: *Semester week hours*	2	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand: *Workload*	90 hours (32 Full-time attendance course of study + 58 Self-study)		

Lernziele / *Learning objectives*

Es besteht ein starkes Bedürfnis, die Menschen, die gesellschaftliche Gemeinschaft und kritische Infrastrukturen und Versorger vor schädigenden Naturereignissen oder von Menschen herbeigeführten außergewöhnlichen Ereignissen zu schützen. Lösungen müssen abgeleitet werden, um eine ausreichende Robustheit und Resilienz der städtischen Infrastruktur für diese außergewöhnlichen Ereignisse mit minimaler Wirkung auf die Normalität zu realisieren. Bisher berücksichtigen normale Regularien und Baurichtlinien diese außergewöhnlichen Ereignisse nicht im Detail. Das erforderliche Fachwissen steht aber zur Verfügung.
Daher sollten die Grundlagen dieses Wissens, welche erforderlich sind um Lösungen abzuleiten, in diesem Kurs beleuchtet werden.

There is strong need to protect people, the societal community and critical infrastructures and utilities against being damaged, destroyed or disrupted by natural disasters or deliberate acts of terrorism. Solutions have to be derived to realize sufficient resilience of the urban infrastructure for rare occasions with minimum effect on normality. Hitherto, normal regulations and building guidelines do not take into account such extraordinary events in detail. But the required specialist knowledge is available.

Hence the basics of this knowledge to derive the required solutions will be explored within this course.

Inhalte Vorlesung / *Content of the lecture*

Vorlesung und Übung

Im Detail sollen die Studierenden folgendes lernen:
• Ingenieurverfahren zur Grenztragfähigkeit von Strukturen
• Druck-Impulsdiagramme zur Schadensbewertung
• Schädigungsmodelle
• Grundlagen der Verwendung numerischer Simulation zur Schadensbewertung
• Überblick numerische Methoden
• Beispiele zum Einsatz numerischer Simulation, Anwendung der Verfahren auf vorhandene Bausubstanz
• Redundanzen, Resttragfähigkeit
• Verfahren und Methoden zur Risikominderung durch Schutzmaßnahmen
• Umsetzungsbeispiele zu Schutzmaßnahmen
• Retrofit: Konzepte, Planungsdesign

Lecture and exercise

In detail students will learn about
- Engineering methods for the assessment of the ultimate bearing capacity of structures
- Pressure-Impulse diagrams for the damage assessment
- Damage models in general
- Fundamentals of numerical simulations for damage assessment
- Overview of numerical methods
- Use cases of numerical Simulations on build infrastructures
- Redundancy and Residual bearing capacity
- Processes and methods for risk reductions
- Examples for effective countermeasures
- Retrofit: Concepts and plan design

Zu erbringende Prüfungsleistung / *Course-based assessment*
Schriftliche Prüfungsleistung / written examination; Referat, Vortrag / presentation

Literatur / *Literature*
tba

Modul / *Module*

Systemtheorie und Regelungstechnik II / Systems theory and automatic control II

Nummer *Number*	11LE50MO-5234		
Modulverantwortlicher *Responsible person*	Prof. Dr. M. Diehl	**Einrichtung** *Organisational unit*	IMTEK; Chair Systemtheorie
Modultyp *Module Type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	3	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 lecture + 1 exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	150 hours (48 hours Full-time attendance course of study + 102 hours Self-study)		

Lernziele / *Learning objectives*

Students understand important structures used in practice and can independently apply the aquired knowledge. In addition, they master fundamental methods to describe, analyse and control discrete-time systems and multivariable systems. Furthermore, students can design model-based controllers and understand important concepts of nonlinear control.

Inhalte Vorlesung / *Content of the lecture*

Based on the Bachelor module "Systemtheorie und Regelungstechnik", advanced methods are discussed to describe, analyze, and control dynamic systems. The course consists of four parts:

The first part focuses on linear single-input single-output (SISO) systems. The methods derived in "systems theory and automatic control I" for continuous-time systems are transferred to discrete-time systems. In particular, the structure of digital control systems using analog-to-digital and digital-to-analog converter are discussed. Furthermore, methods to characterize discrete-time systems are introduced such as difference equations, z-transformation, and z-transfer function. The bilinear transformation is introduced in context of controller design.

In the second part, different control structures and design methods for linear SISO systems are discussed which go beyond the standard control loop presented in the course "systems theory and automatic control I". Concepts for feedforward control and disturbance rejection are presented and the basic structure of a cascade controller is discussed. In addtion, the internal model controller, the compensation controller and the Smith predictor are treated.

In the third part of the lecture, linear multi-input multi-output (MIMO) systems are treated.

The Kalman decomposition is introduced in state space as an important principle to describe the observability and controllability of a MIMO system. Controller design for directly observable systems using pole placement and LQR (Linear Quadratic Regulator) are discussed. Addressing not directly observable systems, the Luenberger observer and the Kalman filter are introduced for state estimation.

The fourth part of the lecture provides an introduction to the control of nonlinear systems. In particular, the concept of Lyapunov stabilty is treated and used to characterize non-linear systems.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination

Literatur / *Literature*

- Lunze, J.: Regelungstechnik 1 - Systemtheoretische Grundlagen, Analyse und Entwurf einschleifiger Regelungen, Springer
- Lunze, J.: Regelungstechnik 2 - Mehrgrößensysteme, Digitale Regelung, Springer
- Unbehauen, H.: Regelungstechnik I - Klassische Verfahren zur Analyse und Synthese linearer kontinuierlicher Regelsysteme, Fuzzy-Regelsysteme, Vieweg + Teubner Verlag
- Unbehauen, H.: Regelungstechnik II - Zustandsregelungen, digitale und nichtlineare Regelsysteme, Vieweg + Teubner Verlag
- Föllinger, O.: Regelungstechnik: Einführung in die Methoden und ihre Anwendung, Hüthig Verlag

Modul / *Module*
Technologische Optionen für die Zukunft der Photovoltaik / Emerging and Future Photovoltaic Technology Options

Nummer *Number*	11LE68MO-4105-ab042018		
Modulverantwortlicher *Responsible person*	Dr. Jan C. Goldschmidt	**Einrichtung** *Organisational unit*	INATECH; external lecturer
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercise	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Solar Energy		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	2 lecture + 2 exercise	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	180 hours (39 hours full-time attendance course of study + 141 hours self-study)		

Lernziele / *Learning objectives*

The overarching goal of this module is to enable the students to participate in research & development of advanced photovoltaic technologies, as well as to critically assess the potential benefit of new PV technologies for a sustainable energy system in an industrial or political context.
The participants of this module will be able to explain how efficiency limitations of the current silicon solar cell technology and the current cost structure of PV electricity motivate the ongoing efforts to develop alternative PV technologies.
The students will be able to name the relevant PV technology options that are currently being investigated, describe their working principle as well as the limitations and challenges these options face.
The students will be able to list critical key indicators for perfomance, potential, market readiness and relevance of a PV technology and to use those to critically assess new emerging PV technologies.

Inhalte Vorlesung / *Content of the lecture*

- Historic development of PV technology and past misconception of alternative PV technologies
- Challenges for the dominant silicon technology: Approaching efficiency limits and system cost structure

- Dye Sensitized-, Organic-, and Perovskite Solar Cells
- Quantum Dots and Nanowire Solar Cells
- Tandem Approaches
- Spectral Management
- The role of Nanophotonics
- Hot Carrier Solar Cells and Thermophotovoltaics
- Thermodynamic limits to future developments
- Disruptive vs. Evolutionary Change
- The importance of efficiency and stability
- Resource limitations and life cycle analysis

Inhalte Übung / *Content of the exercises*

- Cost calculations
- Efficiency calculations
- Assessment of photovoltaic technologies
- Small simulation models for different technologies

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written examination

Zu erbringende Studienleistung / *Coursework*

Attendance of at least 80% of the lectures and exercises.

Literatur / *Literature*

- M. Green, Third Generation Photovoltaics
- J. Nelson, The Physics of Solar Cells
- Würfel, Peter, and Uli Würfel. Physics of solar cells: from basic principles to advanced concepts. John Wiley & Sons, 2009.

Modul / *Module*

Technologien für Mehrfachsolarzellen und Konzentratorphotovoltaik / Multi-junction solar cell technology and concentrator PV

Nummer *Number*	11LE68MO-4103		
Modulverantwortlicher *Responsible person*	A. Bett	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Basic knowledge of semiconductor physics; Solar energy (mandatory module)		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Irregular
Arbeitsaufwand *Workload*	90 hours (28 hours Full-time attendance course of study + 62 hours Self-study)		

Lernziele / *Learning objectives*

Die Anforderungen für Solarzellen mit Wirkungsgraden jenseits des klassischen Shockley-Queisser-Limits zu verstehen; Materialien und Technologien zu Herstellung von Mehrfachsolarzellen zu kennen; Kenntnisse erwerben zu den spezifische Materialanforderungen und zur Charakterisierung von Mehrfachsolarzellen; Anwendungsfelder von Mehrfachsolarzellen techno-ökonomisch zu bewerten können; Verständnis entwickeln um systemische Optimierungsansätze für Konzentratorsysteme durchzuführen

Understanding of challenges for solar cells with efficiencies beyond the classical Shockley-Queisser limits; knowledge about materials and technologies to fabricate multi-junction solar cells; generate understanding on the specific needs in respect to material quality and characterisation techniques for multi-junction solar cells; techno-economic evalution of multi-junction solar cells in concentrating photovoltaic systems; Understanding how to optimize holistically a concentrator system.

Inhalte Vorlesung / *Content of the lecture*

- Konzepte für Mehrfachsolarzellen um die Wirkungsgrade zu erhöhen; unterschiedliche Solarzellenarchitekturen
- Einführung der III-V-Verbindungshalbleiter, Mischkristalle zur Einstellung der Bandlücke, Wachstumstechnologien

- Charakterisierungstechniken für Materialien, Mehrfachsolarzellen und Konzentratormodule
- Einführung in die Konzentratortechnologie: hoch- und niedrig-konzentrierende Systeme
- Komponeten eines Konzentratorsystems: Optik, Zelle, Herstellung
- Konzentratorsystemanalyse mit ökonomischer Bewertung

- Multi-junction solar cell approach to increase the sunlight conversion efficiency, different solar cell architectures
- introduction III-V materials, adjustment of band-gap, growth techniques
- methods for charaterisation of III-V materials, multi-junction solar cells and concentratormodules
- PV concentrator technology: low and high concentration
- componentes of CPV systems: optics, cells, manufacturing
- CPV system analysis including an economical evalution

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination

Literatur / *Literature*

"Solar Cells and Their Applications", L. Fraas, L.Partain, Wiley, 2010; "Advanced Concepts in Photovoltaics", AJ Nozik, G. Conibeer, MC Beard, Royal Society of Chemistry, 2014; "Next Generation Photovoltaics", AB Cristobal Lopez, A. Marti Vega, A. Luque Lopez, Springer Series in Optical Sciences 165, 2012, "Concentrator Phtovoltaics", A Luque, V. Andreev, Springer Verlag, Series in Optical Sciences, 2011

http://www.III-V.de

Modul / *Module*

Theory and Modeling of Materials

Nummer *Number*	07LE33V-MODMAT		
Modulverantwortlicher *Responsible person*	C. Elsässer	**Einrichtung** *Organisational unit*	Physikalisches Institut
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*		**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Theoretical physics and solid-state physics on the level of a BSc in Physics		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 lecture + 1 exercise	**Angebotsfrequenz** *Regular cycle*	Irregularly in summer and winter term
Arbeitsaufwand *Workload*	150 hours		

Lernziele / *Learning objectives*

- Students become able to develop and apply theoretical models to investigate practical problems of the physics of materials
- Students become familiar with theoretical condensed-matter physics and computational modelling and simulation of materials

Inhalte Vorlesung / *Content of the lecture*

The content of each course will be given in the announcement for each semester. The series of one- or two-semester elective-subject lectures introduces theoretical models and computational methods of solid-state physics for the description of many-electron systems, by means of which cohesion and structure, physical, chemical, or mechanical properties of perfect crystals and real materials can be understood qualitatively and calculated quantitatively on a microscopic fundament. The lecture series comprises courses on, e.g., these topics:

- Electronic-structure theory of condensed matter I + II
- Superconductivity I (phenomenology) + II (microscopic theory)
- Theoretical models for magnetic properties of materials
- Theory of atomistic and electronic structures at interfaces in crystals
- etc.

Zu erbringende Prüfungsleistung / *Course-based assessment*

Written or oral examination

Zu erbringende Studienleistung / *Coursework*
Written or oral examination

Literatur / *Literature*
Recommended literature will be announced in each lecture

Modul / *Module*
Thermoelektrik / Thermoelectric

Nummer *Number*	11LE50MO-5715		
Modulverantwortlicher *Responsible person*	Prof. Dr. J. Wöllenstein	**Einrichtung** *Organisational unit*	IMTEK; Chair Dünnschicht-Gassensorik
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	German
Empfohlene Voraussetzungen *Recommended preconditions*	Basic knowledge physics, electrical engineering, microsystem technology and sensor technology		

Empfohlenes Fachsemester *Recommended term of study*	5	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	2 Lecture	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 hours (32 hours Full-time attendance course of study + 58 hours Self-study)		

Lernziele / *Learning objectives*

Das Ziel des Moduls ist die Vermittlung der physikalischen, chemischen, elektrischen Funktionsweise thermoelektrischer Bauelemente und Systeme. Dabei werden aufbauend auf den vermittelten Grundlagen typische Materialsysteme, Modultechnologien und Anwendungen vorgestellt. Die Studierenden sollen den Zusammenhang zwischen der Wirkungsweise, Modul- und Systemdesign, Fertigungsprozessen und dem Einsatz thermoelektrischer Systeme wie Thermogeneratoren, Peltier-Elemente und Thermocouples erlernen.

Inhalte Vorlesung / *Content of the lecture*

Thermoelektrische Anwendungen finden sich in der Temperaturmesstechnik, der Kalorimetrie, der Detektion von Strahlung, der Kühl- und Heiztechnik und der direkten Konversion von Wärmeenergie in elektrischer Energie, den Thermogeneratoren. In der Lecture wird ein grundlegendes Verständnis thermoelektrischer Effekte vermittelt und deren Abhängigkeit von verschiedenen Materialeigenschaften wie zum Beispiel Seebeck- und Peltier-Koeffizient, elektrische Leitfähigkeit und Wärmeleitfähigkeit abgeleitet. Es werden verschiedene Materialsysteme, die sich für die Thermoelektrik besonders eignen, vorgestellt und im Hinblick auf typische Anwendungen bewertet. Der Stand der Technik in der Umsetzung dieser verschiedenen thermoelektrischen Materialien in Module und Systeme wird vorgestellt. Anhand typischer Anwendungsbeispiele werden Modellierung und Entwurf thermoelektrischer Module erörtert.

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Literatur / *Literature*
Begleitend zur Lecture werden die verwendeten Folien zur Verfügung gestellt.

Modul / *Module*

The science of complex systems - fundamentals and applications

Nummer *Number*	11LE68MO-5560		
Modulverantwortlicher *Responsible person*	Dr. Mirko Schäfer	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	• Basic knowledge of the programming language Python • Basic knowledge of matrix and probability theory and differential equations		

Empfohlenes Fachsemester *Recommended term of study*	4	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	180h (in class + preparation of classes)		

Lernziele / *Learning objectives*

After the completion of the course the student is expected to be able to
- identify and explain characteristic properties of complex systems
- discuss problems occuring in different fields (technical, societal, economic, etc.) from an interdisciplinary complex systems perspective
- describe and compare various concepts and models from the science of complex systems
- implement and analyse mathematical complex systems models in the programming language Python

Inhalte Vorlesung / *Content of the lecture*

Theory:
- Fundamentals of complex networks theory
- Bifurcations and chaos in dynamical systems
- Collective phenomena and swarm intelligence
- Fundamentals of game theory

- Agent-based modelling

Applications:
- Market models
- Economics of climate change
- Complexity theory and financial regulation
- The structure and dynamics of cities

Zu erbringende Prüfungsleistung / *Course-based assessment*
None (because interdisciplinary profile)

Zu erbringende Studienleistung / *Coursework*
Written supervised exam **and** exercises

Literatur / *Literature*

- Claudius Gros, "Complex and Adaptive Dynamical Systems, Fourth Edition" (Springer, 2015)
- David Easley, Jon Kleinberg, "Networks, Crowds and Markets" (Cambridge University Press, 2010)

Further literature will be announced in class

Modul / *Module*
Verifikation Digitaler Schaltungen / Verification of Digital Circuits

Nummer: *Number*	11LE13MO-1223		
Modulverantwortlicher: *Responsible person*	Prof. Dr. Christoph Scholl; Prof. Dr. Bernd Becker	**Einrichtung:** *Organisational unit*	IIF
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercise	**Sprache** *Language*	English
Zwingende Voraussetzungen *Mandatory requirements*	None		
Empfohlene Voraussetzungen *Recommended preconditions*	Kenntnisse in Technischer Informatik		

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	4	**Angebotsfrequenz** *Regular cycle*	Irregularly
Arbeitsaufwand *Workload*	180 hours		

Lernziele / *Learning objectives*

Die Studierenden kennen die Grundfragen der formalen Verifikation im Unterschied zur reinen Simulation von Schaltungen und Systemen und können davon ausgehend wichtige algorithmische Techniken anwenden und gegebenenfalls an neue Bedürfnisse anpassen. Sie lernen mögliche Gefahren im Falle des fehlerhaften Entwurfs eingebetteter Systeme zu erkennen und das Instrumentarium zum Nachweis und zur Vermeidung solcher Fehler (insbesondere durch formale Methoden) zu beherrschen.

Inhalte Vorlesung / *Content of the lecture*

Viele moderne Produkte basieren auf mikroelektronischen Komponenten. Oftmals ist das korrekte Funktionieren dieser Produkte lebenswichtig, etwa in Medizintechnik oder Autoelektronik. Daher werden hohe Anforderungen an die Qualität der darin eingesetzten mikroelektronischen Systeme gestellt. Die Anforderungen lassen sich in drei Gruppen unterteilen: (1) Das System muss korrekt entsprechend der Spezifikation entworfen sein. (2) Das gemäß Entwurf physikalisch gefertigte System soll zum Zeitpunkt seiner Herstellung fehlerfrei funktionieren. (3) Darüber hinaus soll das System für einen gegebenen Zeitraum zuverlässig (d.h. ohne Ausfall) eingesetzt werden können.
Während Anforderung (2) durch Testmethoden und Anforderung (3) durch Methoden zur Erhöhung der Ausfallsicherheit behandelt werden, spielen für die Einhaltung von Anforderung (1) Verifikations- und Validierungsmethoden eine Rolle. Der Schwerpunkt der

Vorlesung liegt auf Verifikations- und Validierungsmethoden für digitale Komponenten. Dabei interessiert sowohl der formale Nachweis von Systemeigenschaften als auch die Übereinstimmung des Entwurfs im Vergleich zu einer gegebenen Spezifikation. Es werden zunächst verschiedene existierende Basistechniken zur formalen Verifikation vorgestellt, wie z.B. Decision Diagrams, SAT-Solver und And-Inverter-Graphen. Darauf aufsetzend werden auf symbolischen Methoden beruhende Ansätze zum Äquivalenzvergleich kombinatorischer und sequentieller Schaltungen sowie zur Eigenschaftsprüfung beschrieben.

Inhalte Übung / *Content of the exercises*

Zu erbringende Prüfungsleistung / *Course-based assessment*

written or oral examination

Zu erbringende Studienleistung / *Coursework*

Literatur / *Literature*

- Kropf: "Introduction to Formal Hardware Verification" , Springer, 1999, ISBN 3-540-65445-3
- Clarke, Grumberg, Peled, "Model Checking", MIT Press 1999
- Kropf (Ed.): "Formal Hardware Verification", Springer, 1997, ISBN 3-540-63475-4
- Diverse Originalarbeiten
- Presentation of powerpoint slides. Slides and exercise sheets can be downloaded from the course website.

Modul / *Module*

Werkstoffdynamik / Dynamics of Materials: Material Characterization

Nummer *Number*	11LE68MO-5118		
Modulverantwortlicher *Responsible person*	S. Hiermaier M. May	**Einrichtung** *Organisational unit*	INATECH
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture	**Sprache** *Language*	English

Empfohlenes Fachsemester *Recommended term of study*	2	**ECTS-Punkte** *ECTS credits*	5
SWS *Semester week hours*	2 lecture + 2 exercises	**Angebotsfrequenz** *Regular cycle*	Summer term
Arbeitsaufwand *Workload*	150 hours (56 hours Full-time attendance course of study + 94 hours Self-study)		

Lernziele / *Learning objectives*

Lernziel des Moduls ist die Kenntnis experimenteller und numerischer Grundlagen zum mechanischen Verhalten von Werkstoffen bei dynamischer Belastung. Mit den erarbeiteten Methoden können die Studierenden Spannungs-Verzerrungs-Beziehungen in Abhängigkeit von der Belastungsgeschwindigkeit bestimmen und in numerischen Verfahren als Materialmodell implementieren. Übergeordnetes Lernziel der Lehrveranstaltung ist die Beherrschung der Grundfähigkeiten zur experimentellen Charakterisierung und numerischen Model lierung dynamischen Materialverhaltens.

Aim of the course is the knowledge of experimental and numerical basics on the mechanical behaviour of materials under dynamic loading conditions. It enables the students in deriving strain-rate dependent stress-strain relations and in implementing the resulting constitutive models into numerical codes. General aim is the basic ability for experimental characterization and numerical modelling of dynamic material behaviour.

Inhalte Vorlesung / *Content of the lecture*

Werkstoffcharakterisierung:

- Statische und dynamische Werkstoffprüfung
- Die Verzerrungsrate als Maß für die Materialdynamik
- Nutzung von Wellenausbreitung zur Materialprüfung

- Verzerrungsratenabhängige Elastizität, Plastizität und Versagen
- Mathematische Modellierung des Materialverhaltens
- Auftreten von Stoßwellen in Festkörpern
- Zustandsgleichung als Komponente des Spannungstensors
- Nichtlineare Zustandsgleichungen

Numerik dynamischer Deformationsprozesse:

- Räumliche und zeitliche Diskretisierung dynamischer Prozesse in Festkörpern
- Finite Differenzen Verfahren in Raum und Zeit
- Finite Element Verfahren
- Implizite und explizite Zeitintegration
- Netzfreie Diskretisierungsverfahren

Materials Characterisation:

- *Static and dynamic testing of materials*
- *Strain rate as a measure for dynamic material behaviour*
- *Use of elastic waves for materials testing*
- *Strain-rate dependent elasticity, plasticity, and failure*
- *Mathematical modelling of material failure*
- *Shock waves in solids*
- *Equations of state and the total stress tensor*
- *Nonlinear Equations of state*

Numerical modelling of dynamic deformation

- *Spatial and Time Discretization of dynamic deformation of solids*
- *Finite differences for space and time*
- *Basics of the Finite Element method*
- *Implicit and explicit time integration*
- *Basics of meshfree discretization methods*

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral exam

Literatur / *Literature*
• S. Hiermaier, "Structures under Crash and Impact", Springer, 2008

Modul / *Module*
Wind Energy Systems / Windenergiesysteme

Nummer *Number*	11LE50MO-5256		
Modulverantwortlicher *Responsible person*	Prof. Dr. M. Diehl	**Einrichtung** *Organisational unit*	IMTEK
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercise	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Systems and Control		
Zwingende Voraussetzungen *Mandatory requirements*	Basic Physics and Mathematics Courses from BSc		

Empfohlenes Fachsemester *Recommended term of study*	2 or 3	**ECTS-Punkte** *ECTS credits*	6
SWS *Semester week hours*	3 Lecture + 1 exercise (2 slots with 2 hours per week, exercises only every other week)	**Angebotsfrequenz** *Regular cycle*	Irregularly
Arbeitsaufwand *Workload*	18h		

Lernziele / *Learning objectives*

Studierende verstehen die physikalischen Grundlagen der Windenergie und die Technologie moderner Windenergiesysteme.

Students understand the physical principles of wind energy and the technology of modern wind energy systems.

Inhalte Vorlesung / *Content of the lecture*

- Globale Windenergieressource
- Aerodynamische Prinzipien von Windturbinen
- Design moderner Windturbinen
- Regelung moderner Windturbinen
- Das elektrische System von Windturbinen
- Alternative Konzepte und Höhenwindenergie

- *Global wind energy resource*
- *Aerodynamic principles of wind turbines*
- *Design of modern wind turbines*

- *Control of modern wind turbines*
- *The electrical system of wind turbines*
- *Alternative concepts and airborne wind energy*

Inhalte Übung / *Content of the exercises*
Die Übung vertieft das Verständnis für den Stoff der Vorlesung. *The exercises help deepen the understanding of the contents of the lecture.*

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Zu erbringende Studienleistung / *Coursework*
If any, they will be announced during the first lecture.

Literatur / *Literature*
"Wind Energy Handbook" by T. Burton, N. Jenkins, D. Sharpe, E. Bossanyi, 2nd edition, Wiley, 2011 https://www.syscop.de/teaching

Modul / *Module*
Zuverlässigkeitstechnik / Reliability Engineering

Nummer *Number*	11LE50MO-5214		
Modulverantwortlicher *Responsible person*	Prof. Dr. J. Wilde	**Einrichtung** *Organisational unit*	IMTEK; Chair Aufbau- und Verbindungstechnik
Modultyp *Module type*	Elective Module	**Moduldauer** *Module duration*	1 term
Zugehörige Lehrveranstaltungen *Connected events*	Lecture and exercises	**Sprache** *Language*	English
Empfohlene Voraussetzungen *Recommended preconditions*	Basic understanding in mathematics (statistics) as well as materials sciences		

Empfohlenes Fachsemester *Recommended term of study*	5	**ECTS-Punkte** *ECTS credits*	3
SWS *Semester week hours*	1 Lecture + 1 Exercises	**Angebotsfrequenz** *Regular cycle*	Winter term
Arbeitsaufwand *Workload*	90 hours (32 hours full-time attendance course of study + 58 hours self-study)		

Lernziele / *Learning objectives*

It is the aim, that after this module, the student will:

- have elementary capabilities to solve praxis-relevant.
- know how experiments can be replaced by simulation and what the necessary input data are.
- be able to evaluate Sustainable Systems and more complex electronic and mechatronic systems including software.
- Furthermore it is expected that the student will have improved capabilities in the risk analysis of hazardous applications.
- Also the students will be able to report the corresponding results.

Inhalte Vorlesung / *Content of the lecture*

1. Definitions
    - 1.1 Quality, dependability, reliability and safety
    - 1.2 Benchmarks for dependability, availability und lifetime
    - 1.3 Statistical description of reliability
2. Dependability of mechanical systems
    - 2.1 Example 1: The ICE-crash at Eschede
    - 2.2 Loads on mechanical components
    - 2.3 Risk factors: notches and cracks
    - 2.4 Fatigue - Woehler's S-N-curve concept
    - 2.5 Computation of operational strength
3. Reliability of electronic hardware

- 3.1 Automotive electronics: architecture, requirements and quality level
- 3.2 Reliability of electronic devices, data

4. Reliability data-bases
5. Reliability of systems
   - 5.1 Reliability block-diagram (failure-rate analysis)
   - 5.2 Overview of failure mode analyses
   - 5.3 Fault tree analysis (FTA)
   - 5.4 State-Space: A general method to compute Rs(t) and Fs(t)
6. Reliability of repairable systems
   - 6.1 Definitions
   - 6.2 Repair rate
   - 6.3 Availability
   - 6.4 Markov-Chains and Markov-Processes
7. Software reliability
   - 7.1 Examples of software-induced accidents
   - 7.2 Probability of software faults
   - 7.3 Reliability models for software
   - 7.4 Misjudgements concerning software use
8. Human factors
9. Pre-requisites for development processes
10. Standards and legislation for medical devices

Zu erbringende Prüfungsleistung / *Course-based assessment*
Written or oral examination

Literatur / *Literature*

- Reliability Engineering, Alessandro Birolini, 4th ed., Springer, 2004, ISBN: 3-540-40287-X
- Fehlerbaumanalyse in Theorie und Praxis, Frank Edler, Michael Soden, René Hankammer, 1. Aufl., Springer Vieweg, 2015, ISBN: 978-3-662-48166-0

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