Module Guide / Modulhandbuch

TECHNISCHE UNIVERSITÄT DARMSTADT

Department of Materials and Geo Sciences

Fachbereich Material- und Geowissenschaften

Course of Studies Master of Science Materials Science
Studiengang Master of Science Materialwissenschaft

Table of Contents

Voluntary Courses

Module: Career Coaching
responsible: **Dean of Studies Materials Science**

Course [M.CC] Workshop: Career Coaching	**Module** Career Coaching	**Instructor(s)** All Professors Materials Science
Form of Teaching / Credit Hours workshop	**Credit Points** 0	**Language** English
Expenditure of Work One-day block course at the beginning of the third semester.		
Module Offered Every WS	**Recommended Semester*** 3rd Semester	**Weekday/Time/Place*** see University Catalog
Examination Requirements Voluntary course		
Content of Teaching and Examination • Overall view on career possibilities in material science • Illustration of a typical Ph.D. • Overall view on career possibilities for a materials scientist working in other fields • Career examples of alumni		
Learning Outcomes, Qualification, and Competence Aims An overall view on career possibilities in material science and as a materials scientist is gained. Knowledge is acquired whom to ask or address about which career direction. The candidate acquires the ability to plan career decisions in a rational way.		
Annotations / Usability of Module* M.Sc. Materials Science: Voluntary Course		
Prerequisites none	**Literature*** none	
Form of Examination* none	**Length of Examination***	
Grade Composition* none		

* optional information

Compulsory Modules

Module 1: Research Labs I and II
responsible: **Prof. Dr. R. Riedel**

<table>
<tr><td colspan="2">Course
[M.RL1] Research Lab I</td><td colspan="2">Module
Research Labs I and II</td><td>Instructor(s)
All Professors Materials Science</td></tr>
<tr><td colspan="2">Form of Teaching / Credit Hours
Lab/4</td><td colspan="2">Credit Points
4</td><td>Language
English</td></tr>
<tr><td colspan="5">Expenditure of Work
Lab: 60 h, H: 60 h; Sum: 120 h</td></tr>
<tr><td>Module Offered
Every WS</td><td colspan="3">Recommended Semester*
1st Semester</td><td>Weekday/Time/Place*
see University Catalog</td></tr>
<tr><td colspan="5">Examination Requirements
Study Work</td></tr>
<tr><td colspan="5">Content of Teaching and Examination
Experiments:
• Advanced elektrochemical analytics
• Modern X-ray diffraction (XRD) methods: Thin films
• Advanced pulsed laser deposition (PLD)
• Advanced ceramics (e.g. silicon based)</td></tr>
<tr><td colspan="5">Learning Outcomes, Qualification, and Competence Aims
In experiments with partly open results, the candidate gets used to modern state-of-the-art scientific equipment in materials science. The experiments are performed using the equipment of the involved research groups, making sure that every student is exposed to scientific research groups.</td></tr>
<tr><td colspan="5">Annotations / Usability of Module*
M.Sc. Materials Science: Compulsory Course</td></tr>
<tr><td>Prerequisites
none</td><td colspan="4">Literature*
Given in the introduction of each experiment</td></tr>
<tr><td colspan="3">Form of Examination*
attestation</td><td colspan="2">Length of Examination*</td></tr>
<tr><td colspan="5">Grade Composition*
pass/non pass</td></tr>
</table>

* optional information

<table>
<tr><td>Course
[M.RL2] Research Lab II</td><td colspan="2">Module
Research Labs I and II</td><td>Instructor(s)
All Professors Materials Science</td></tr>
<tr><td>Form of Teaching / Credit Hours
Lab/4</td><td colspan="2">Credit Points
4</td><td>Language
English</td></tr>
<tr><td colspan="4">Expenditure of Work
Lab: 60 h, H: 60 h; Sum: 120 h</td></tr>
<tr><td>Module Offered
Every SS</td><td colspan="2">Recommended Semester*
2nd Semester</td><td>Weekday/Time/Place*
see University Catalog</td></tr>
<tr><td colspan="4">Examination Requirements
Study Work</td></tr>
<tr><td colspan="4">Content of Teaching and Examination
Experiments:
Characteristics of ferroelectric materials
Organic thin film transistors (TFT)
Barrier formation at semiconductor hetero interfaces
Dielectric response and optical materials properties
Kinetics of diffusion-dominated transitions: hardening of aluminum alloys</td></tr>
<tr><td colspan="4">Learning Outcomes, Qualification, and Competence Aims
In experiments with partly open results, the candidate gets used to modern stat-of-the-art scientific equipment in materials science. The experiments are performed using the equipment of the involved research groups, making sure that every student is exposed to scientific research groups.</td></tr>
<tr><td colspan="4">Annotations / Usability of Module*
M.Sc. Materials Science: Compulsory Course</td></tr>
<tr><td>Prerequisites
none</td><td colspan="3">Literature*
Given in the introduction of each experiment</td></tr>
<tr><td colspan="2">Form of Examination*
attestation</td><td colspan="2">Length of Examination*</td></tr>
<tr><td colspan="4">Grade Composition*
pass/non pass.</td></tr>
</table>

* optional information

Module 2: Materials Engineering

responsible: **Prof. Dr. O. Gutfleisch**

Course [M.ME] Materials Engineering	**Module** Materials Engineering	**Instructor(s)** O. Gutfleisch, W. Ensinger, J. Rödel
Form of Teaching / Credit Hours L/3	**Credit Points** 5	**Language** English
Expenditure of Work Lecture: 45 h, Homework: 45 h, Preparation for Examination: 60 h; Sum 150 h		
Module Offered Every WS	**Recommended Semester*** 1st Semester	**Weekday/Time/Place*** see University Catalog
Examination Requirements Graded Examination		
Content of Teaching and Examination • Material extraction • Design of components • Powder metallurgy / sintering techniques • Shape forming • Chip removing processes • Joining • Coating technologies • Optimization of material properties		
Learning Outcomes, Qualification, and Competence Aims The students get a first insight into material extraction and subsequent manufacturing of materials and components via state-of-the-art technologies such as melt metallurgy and powder metallurgy. This includes the application and use of the relevant theories in this field of research. He / she is able to remember the fundamental correlation between the processing route of components and related material properties. He / she acquires a first qualification to choose material specific processing routes for the design and manufacturing of components for the desired applications. Finally, he/she has a medium level competence to select and apply appropriate coating and joining technologies as well as heat treatments for optimization of material and component performance. The student also gets a first insight into rapid prototyping techniques.		
Annotations / Usability of Module* M.Sc. Materials Science: Compulsory Course		
Prerequisites fundamentals in material science and engineering	**Literature*** 1. Werkstoffwissenschaft und Fertigungstechnik. Eigenschaften, Vorgänge, Technologien. Ilschner, Singer. Springer-Verlag, Berlin 2. Manufacturing with Materials, Edwards, Endean, Butterworth 3. Materials Science and Engineering, R. W. Cahn et al. VCH-Verlag 4. Handbuch der Fertigungstechnik, G. Spur, Hanser-Verlag 5. The Production of Inorganic Materials, J. W. Evans, L. C. DeJonghe, Mc Millan 6. Materials for Engineering, J. W. Martin. The Institute of Materials, London 7. Werkstoffkunde und Werkstoffprüfung, W. Domke. Verlag W. Girardet, Essen 8. Werkstofftechnik – Teil 2: Anwendung, W. Bergmann. Hanser Studien Bücher	
Form of Examination* oral examination or written exam	**Length of Examination*** 30 min oral or 60 min written	
Grade Composition* 100% oral examination or written exam		

* optional information

Module 3: Surfaces and Interfaces

responsible: **Prof. Dr. W. Jaegermann**

Course	**Module**	**Instructor(s)**
[M.SIE] Surface and Interface Engineering	Surfaces and Interfaces	W. Jaegermann, A. Klein
Form of Teaching / Credit Hours L/3	**Credit Points** 5	**Language** English

Expenditure of Work
Lecture: 45 h, Homework: 45 h, Preparation for Examination: 60 h; Sum 150 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every WS	1st Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- surfaces of solids: thermodynamics of surface formation, structure of surfaces, electronic structure of surface and surface potentials
- kinetics of surface reactions: physisorption and chemisorption, surface diffusion, surface reactions and catalysis
- internal surfaces: structural models, thermodynamics of internal surfaces, epitaxy and growth modes
- solid/electrolyte interfaces: thermodynamics and electrochemical double layers, thermodynamics of electrochemical reactions, kinetics of electrochemical reactions, corrosion and corrosion modes

Learning Outcomes, Qualification, and Competence Aims
The student is able to understand and treat the specific effects of surfaces and interfaces in materials science, he/she differentiates between thermodynamically and kinetically determined properties, he/she knows the important terms and definitions and related theoretical concepts used in surface/interface science and electrochemistry, he/she has reached a conceptual understanding how surfaces/interfaces affect the properties of presented devices, he/she will reach a materials science related understanding of electrochemical processes, he/she will be able to transfer this knowledge to any future envisaged problems and materials, the student has reached the competence to differentiate between bulk and surface effects in devices and to correlate them with material's properties, he/she is qualified to evaluate experimental and theoretical methods in his/her possible future research involving surface/interface effects and electrolyte interfaces, he/she will have the competence to follow advanced textbooks and scientific literature.

Annotations / Usability of Module*
M.Sc. Materials Science: Compulsory Course

Prerequisites	**Literature***
Elementary knowledge in physics, especially quantum mechanics and solid state physics	1. H. Lüth, "Surfaces and Interfaces of Solid Materials", Springer Verlag (1995) 2. K. Christmann, "Introduction to Surface Physical Chemistry", Steinkopff Verlag Darmstadt, Springer Verlag New York (1991) 3. H.D. Dörfler, "Grenzflächen und Kolloidchemie" VCH-Verlagsgesellschaft (1994) 4. Zangwill, "Physics at Surfaces", Cambridge University Press 5. E.S. Machlin, "Thermodynamics and Kinetics", Columbia University New York 6. M.Henzler, W.Göpel, "Oberflächenphysik des Festkörpers", Teubner Stuttgart (1991) 7. M.A. Herman, H. Sitter, "Molecular Beam Epitaxy", Springer-Verlag (2nd Ed.) 8. Carl H. Hamann, W. Vielstich "Elektrochemie", Wiley VCH, (3. Aufl.) 9. Helmut Kaesche, "Die Korrosion der Metalle", Springer-Verlag (3. Aufl.)

Form of Examination*	**Length of Examination***
oral examination or written exam	30 min oral or 60 min written

Grade Composition*
100% oral examination or written exam

* optional information

Module 4: Quantum Mechanics for Materials Science

responsible: **Prof. Dr. H. v. Seggern**

Course [M.QM] Quantum Mechanics for Materials Science	**Module** Quantum Mechanics for Materials Science	**Instructor(s)** H. von Seggern, L. Alff, W. Donner, K. Albe, H. Rauh, A. Klein
Form of Teaching / Credit Hours L/2 and E/1	**Credit Points** 5	**Language** English
Expenditure of Work Lecture: 30 h, Homework: 60 h, Exercises: 15 h, Preparation for Examination: 45 h ; Sum 150 h		
Module Offered Every WS	**Recommended Semester*** 1st Semester	**Weekday/Time/Place*** see University Catalog
Examination Requirements Graded Examination		
Content of Teaching and Examination • Historical background • Diffraction experiments • Schrödinger equation and quantum mechanical properties • The H- atom and H_2-molecule, tunneling, harmonic oscillator • LCAO model: from finite to infinite systems, the Bloch function • Density of states in two and three dimensions, population density, Fermi statistics • Bandgaps and their origin • Transport equation of electrons in external fields • Theory of free electrons		
Learning Outcomes, Qualification, and Competence Aims The successful students are able to recognize basic quantum mechanical phenomena. The students are able to derive and calculate simple quantum mechanical problems and are able to use them in daily problems. The students will be able to understand the nature of binding and the electronic structure of atoms, molecules and solids. The students are qualified to apply the theory to the evaluation of the electronic structure of atoms, molecules and solids and are able to describe charge transport in a quantum mechanical manner. The students have a first insight into modern research in quantum mechanics and their knowledge allows them to follow advanced textbooks and scientific literature.		
Annotations / Usability of Module* M.Sc. Materials Science: Compulsory course		
Prerequisites Physical Chemistry I, Solid State Properties I and II recommended	**Literature*** 1. Ch. Kittel: Introduction into solid state physics, John Wiley and Sons (1996) 2. H. Ibach, H. Lüth: Solid state physics, Springer Verlag (2002) 3. A. Sutton: Electronic structure of materias, Clarendon Press (1993) 4. P.W. Atkins, R.S.Friedman: Molecular Quantum Mechanics, Oxford University Press (2000) 5. R. Feynman: The Feynman lectures Vol. III, Addision-Wesley Publishing Company (1989). 6. Franz Schwabl, Advanced Quantum Mechanics, Springer Verlag (2008)	
Form of Examination* oral examination or written exam	**Length of Examination*** 30 min oral or 60 min written	
Grade Composition* 100% oral examination or written exam		

* optional information

Module 5: Seminar: Research Topics in Materials Science

responsible: **All Professors Materials Science**

Course [M.RTMS] Seminar: Research Topics in Materials Science	**Module** Seminar: Research Topics in Materials Science	**Instructor(s)** All professors
Form of Teaching / Credit Hours S/2	**Credit Points** 2	**Language** English
Expenditure of Work Seminar: 30 h, Preparation of Talk: 30 h; Sum 60 h		
Module Offered Every WS	**Recommended Semester*** 1st Semester	**Weekday/Time/Place*** see University Catalog
Examination Requirements Seminar talk		
Content of Teaching and Examination • Topics are given to elaborate on in a seminar talk. These topic are related to actual research areas in materials science. Each set of topics is coherent within a certain field of materials science. The seminar is designed to help to bridge the gap between the scientific education and textbooks and scientific reseach and published papers. • In the discussion section, students have to defend their seminar and should actively contribute to the discussion of other seminars. In the discussion the link between the talks should be reflected.		
Learning Outcomes, Qualification, and Competence Aims The student gains the ability to approach a scientific topic by accumulating information from textbooks and scientific literature. Ability to sort the information and present it to other students at a similar level of knowledge in a useful way. Learning to ask useful and the right questions to scientific talks. Drive to participate in discussion and drawing lines between different talks.		
Annotations / Usability of Module* M.Sc. Materials Science: Compulsory Course		
Prerequisites none	**Literature*** Current research articles and advanced topics according to individual topics.	
Form of Examination* Seminar talk	**Length of Examination*** 30 min	
Grade Composition* pass/non pass		

* optional information

Module 6: Advanced Methods of Materials Science

responsible: **Prof. Dr. W. Donner**

Course [M.AM] Advanced Methods of Materials Science	**Module** Advanced Methods of Materials Science	**Instructor(s)** W. Donner, W. Ensinger
Form of Teaching / Credit Hours L/3 and E/1	**Credit Points** 6	**Language** English

Expenditure of Work
Lecture: 45 h, Homework: 60 h, Exercises: 15 h, Preparation for Examination: 60 h; Sum 180 h

Module Offered Every SS	**Recommended Semester*** 2nd Semester	**Weekday/Time/Place*** see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Small Angle Scattering
- Scattering from Amorphous Materials
- Diffraction from Nanocrystals
- Thin Film Diffraction
- Photoelectron Spectroscopy
- Mass Spectrometry
- Rutherford Backscattering Spectrometry
- Nuclear Reaction Analysis
- Elastic Recoil Detection
- Activation Analysis

Learning Outcomes, Qualification, and Competence Aims
The student knows the fundamentals of various methods of structural and elemental analysis, their advantages and disadvantages. He/she is able to select an appropriate technique for a given analytical problem. The course prepares the students for the practical courses, where they perform analytical experiments on their own. The methods presented in the course represent the state of the art in scattering and spectrometry; therefore the students will be able to critically judge the validity of experimental results in the scientific literature.

Annotations / Usability of Module*
M.Sc. Materials Science: Compulsory Course

Prerequisites “Methods of Materials Science” or similar course recommended	**Literature*** 1. Small Angle Scattering, Glatter & Kratky, ebook 2. Underneath the Bragg Peaks, Egami & Billinge, ebook 3. High Resolution X-ray Scattering, Holy, Pietsch, Baumbach, Springer 4. An Introduction to Surface Analysis by XPS and AES, Wolstenholme, ebook 5. Inorganic Mass Spectrometry, Becker, ebook 6. Atomic and Nuclear Analytical Methods, Verma, ebook

Form of Examination* oral examination or written exam	**Length of Examination*** 30 min oral or 60 min written

Grade Composition*
100% oral examination or written exam

* optional information

Module 7: Theoretical Materials Science

responsible: **Prof. Dr. K. Albe**

Course	**Module**	**Instructor(s)**
[M.TCM] Theoretical Concepts and Methods	Theoretical Materials Science	K. Albe, H. Rauh
Form of Teaching / Credit Hours L/3 and E/1	**Credit Points** 6	**Language** English

Expenditure of Work
Lecture: 45 h, Homework: 60 h, Exercises: 15 h, Preparation for Examination: 60 h; Sum 180 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every SS	2nd Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Balance equations of mechanics and thermodynamics
- Free energy of non-uniform materials
- Fluctuations and stability
- Linear non-equilibrium thermodynamics
- Transition state theory and transport processes
- Statistical mechanics models for materials
- Quantum statistical mechanics
- Optimization techniques
- Ordinary differential equations in materials science
- Boundary value problems in materials science

Learning Outcomes, Qualification, and Competence Aims
The student gains fundamental insights into the key concepts of non-equilibrium thermodynamics, continuum mechanics and (quantum) statistical mechanics relevant for materials science. He/she is able to identify and apply appropriate theoretical concepts for solving materials science problems related to properties and processing of materials. The students are acquainted to numerical methods and capable to solve boundary value problems, ordinary differential equations and transport equations. His/her knowledge allows him/her to follow advanced textbooks and scientific literature on theoretical methods in materials science.

Annotations / Usability of Module*
M.Sc. Materials Science: Compulsory Course

Prerequisites
Quantum Mechanics for Materials Science recommended

Literature*

1. R.B. Balluffi, S.M. Allen, W. C. Carter, *Kinetics of Materials*, Wiley (2005)
2. P. Haupt, *Continuum Mechanics and Theory of Material,* Springer
3. JR. Acton, P.T. Squire, *Solving Equations with Physical Understanding*, Adam Hilger, Bristol (1985)
4. D. Kondepudi, I. Prigogine, Modern Thermodynamics: *From heat engines to dissipative structures,* Wiley *(1998)*
5. D. C. Wallace, *Thermodynamics of Crystals,* Dover (1998)
6. R.K. Pathria, *Statistical Mechanics*, Elevier Butterworth-Heinemann (2005)
7. Rob Philips, *Crystals, Defects and Microstructures*, Cambridge (2001)

Form of Examination*	**Length of Examination***
oral examination or written exam	30 min oral or 60 min written

Grade Composition*
100% oral examination or written exam

* optional information

Module 8: Advanced Research Lab

responsible: **All Professors Materials Science**

Course [M.ARL] Advanced Research Lab	**Module** Advanced Research Lab	**Instructor(s)** All Professors Materials Science
Form of Teaching / Credit Hours Lab/24	**Credit Points** 12	**Language** English
Expenditure of Work Lab: 360 h		
Module Offered Every WS	**Recommended Semester*** 3rd Semester	**Weekday/Time/Place*** To be agreed upon
Examination Requirements Study Work		
Content of Teaching and Examination **Experiments:** Each working group offers scientific tasks which are part of their research program. These tasks have no fixed solution, the solution has to be developed in an interplay between student and the involved members of the research group.		
Learning Outcomes, Qualification, and Competence Aims The student is exposed to a controlled research activity within a real scientific working group. He gains the ability to understand a scientific problem from its different aspects, and how a limited research task is connected to more general and larger research objectives. The student gains experience to judge which individual type of research matches his/her individual interest and capabilities. As a result the student has the competence to choose a suited topic for the master thesis.		
Annotations / Usability of Module* M.Sc. Materials Science: Compulsory Course		
Prerequisites none	**Literature*** Given according to the individual tasks. The student has to find the relevant literature as part of the task.	
Form of Examination* oral task and result summary	**Length of Examination*** 20 min	
Grade Composition* pass/non-pass		

* optional information

Course [M.ARLS] Advanced Research Lab Seminar	**Module** Advanced Research Lab	**Instructor(s)** All Professors Materials Science
Form of Teaching / Credit Hours S/2	**Credit Points** 3	**Language** English
Expenditure of Work S: 30 h, H: 60 h; Sum 90 h		
Module Offered Every WS	**Recommended Semester*** 3rd Semester	**Weekday/Time/Place*** To be agreed upon
Examination Requirements Study Work		
Content of Teaching and Examination The students have to hand out a written report of their lab work and present a talk summarizing their work.		
Learning Outcomes, Qualification, and Competence Aims The students get acquainted to present their results in front of scientist which are working in the same field of research. The student learns to present in a clear and ordered way, understands how to use modern means of presentation such as animated images etc. The student gets used to defend his/her work against critical questions.		
Annotations / Usability of Module* M.Sc. Materials Science: Compulsory Course		
Prerequisites none	**Literature*** Given according to the individual tasks. The student has to find the relevant literature as part of the task.	
Form of Examination* oral task and result summary	**Length of Examination*** 20 min	
Grade Composition* pass/non-pass		

* optional information

Modul 9: Master Thesis and Defense

responsible: All Professors Materials Science

Course [M.THE] Master Thesis	**Module** Master Thesis and Defense	**Instructor(s)** All Professors Materials Science
Form of Teaching / Credit Hours Thesis	**Credit Points** 27	**Language** English
Expenditure of Work Project Work: 6 months, 810 h		
Module Offered Every Semester	**Recommended Semester*** 4th Semester	**Weekday/Time/Place*** Full time
Examination Requirements Graded Examination		
Content of Teaching and Examination • Familiarization with the subject and setup of a work schedule. • Experimental and/or theoretical work on a scientific subject. • Documentation of the results by authoring the Master thesis. • Presentation of the results in a talk with subsequent scientific discussion.		
Learning Outcomes, Qualification, and Competence Aims The student knows the foundations about a current, usually research related question in materials science. He/she knows structure and composition of scientific publications. He/she is able to apply acquired knowledge and qualifications to specific scientific topics with newly acquired methods and means in order to independently work on scientific problems in a sufficient depth and breadth. He/she is able to autonomously create documentations and presentations about his/her research work and results.		
Annotations / Usability of Module* M.Sc. Materials Science: Compulsory Course		
Prerequisites 75 CP from Compulsory and Elective Courses	**Literature*** As announced by Advisor	
Form of Examination* written (Master Thesis)	**Length of Examination***	
Grade Composition* Scientific Work with written Thesis (100%). The public defense with discussion has to be passed.		

* optional information

Course [M.DEF] Master Defense	**Module** Master Thesis and Defense	**Instructor(s)** All Professors Materials Science
Form of Teaching / Credit Hours Public Talk	**Credit Points** 3	**Language** English
Expenditure of Work H: 90 h		
Module Offered Every Semester	**Recommended Semester*** 4th Semester	**Weekday/Time/Place*** To be agreed upon
Examination Requirements Study Work		
Content of Teaching and Examination Public presentation of the results of the Master thesis with subsequent scientific discussion.		
Learning Outcomes, Qualification, and Competence Aims The student is able to adequately present his/her results and to discuss and defend them in a public scientific environment.		
Annotations / Usability of Module* M.Sc. Materials Science: Compulsory Course		
Prerequisites 75 CP from Compulsory and Elective Courses	**Literature*** As announced by Advisor	
Form of Examination* oral (talk)	**Length of Examination*** 60 min	
Grade Composition* Scientific Work with written Thesis (100%). The public defense with discussion has to be passed.		

* optional information

Materials Science Advanced Elective Courses

Computational Materials Science

responsible: **Prof. Dr. K. Albe**

<table>
<tr><td colspan="2">Course
[M.CMS] Computational Materials Science</td><td colspan="2">Module
Materials Science Advanced Elective Courses</td><td>Instructor(s)
K. Albe</td></tr>
<tr><td colspan="2">Form of Teaching / Credit Hours
L/2 and E/1</td><td colspan="2">Credit Points
4</td><td>Language
English</td></tr>
<tr><td colspan="5">Expenditure of Work
Lecture: 30 h, Excersises: 15h, Homework: 45 h, Preparation for Examination: 30 h: Sum: 120 h</td></tr>
<tr><td>Module Offered
Every WS</td><td colspan="2">Recommended Semester*
3rd Semester</td><td colspan="2">Weekday/Time/Place*
see University Catalog</td></tr>
<tr><td colspan="5">Examination Requirements
Graded Examination</td></tr>
<tr><td colspan="5">Content of Teaching and Examination
• Introduction to Basic Concepts of Thermodynamics and Statistics
• Molecular Dynamics Method: Principles
• Equilibrium Thermodynamics and MD-Simulations
• Overview of Analytic Potentials
• Transport Processes and MD-Simulations
• Monte-Carlo Methods
• Kinetic Monte-Carlo Methods
• Bridging Time Scales: Accelerated Dynamics
• Foundations of Density Functional Theory
• Kohn-Sham Ansatz
• Functionals for Exchange and Correlation
• Electronic Structure Calculations: PlaneWaves, LCAO, …</td></tr>
<tr><td colspan="5">Learning Outcomes, Qualification, and Competence Aims
The student knows fundamentals, possible applications and limitations of computational methods relevant in materials science. He/she has a basic understanding of the underlying numerical methods and algorithms and has gained practical experience with standard software packages like LAMMPS for molecular dynamics simulations. ABINIT for electronic structure calculations and software tools for data analysis (OVITO). He/she will have the competence to follow advanced textbooks and scientific literature on atomistic methods in materials science.</td></tr>
<tr><td colspan="5">Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Courses</td></tr>
<tr><td>Prerequisites
Quantum Mechanics for Materials Science and Theoretical Materials Science recommended</td><td colspan="4">Literature*
1. M.P. Allen and D.J. Tildesley, Computer Simulation of Liquids, Clarendon Press (1987)
2. D.C. Rapaport, The Art of Molecular Dynamics Simulation, Cambridge (1995)
3. D. Frenkel, B. Smit, Understanding Molecular Simulation, Academic Press (1996)
4. D. Raabe, Computational materials science: the simulation of materials
5. microstructures and properties, Wiley-VCH (1998)
6. K. Binder, Application of the Monte Carlo Method in Statistical Physics, Springer (1984)
7. K. Binder, The Monte Carlo Method in Condensed Matter Physics, Springer (1992)
8. R. Dreizler, E. Gross, Density Functional Theory, Plenum Press (1995).
9. W. Koch, M. C. Holthausen, A Chemist's Guide to Density Functional Theory, Wiley-VCH, Weinheim (2002)
10. E. Kaxiras, Atomic and Electronic Structure of Solids, Cambridge (2003)
11. R. Martin: Electronic Structure: Basic Theory and Practical Methods, Cambridge (2004)
12. Rob Philips, Crystals, Defects and Microstructures, Cambridge (2001)
13. http://www.abinit.org
14. http://lammps.sandia.gov
15. http://www.ovito.org</td></tr>
<tr><td colspan="3">Form of Examination*
oral</td><td colspan="2">Length of Examination*
30 min</td></tr>
<tr><td colspan="5">Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.</td></tr>
</table>

* optional information

Density Functional Theory: A Practical Introduction

responsible: **Prof. Dr. K. Albe**

Course [M.DFT] Density Functional Theory: A Practical Introduction	**Module** Materials Science Advanced Elective Courses	**Instructor(s)** K. Albe
Form of Teaching / Credit Hours L/2 and E/1	**Credit Points** 4	**Language** English

Expenditure of Work
Lecture: 30 h, Homework: 45 h, Exercises: 15 h, Preparation for Examination: 30 h; Sum 120 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every SS	2nd Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination
Density functional theory (DFT) is one of the most frequently used computational tools for studying and predicting the properties of isolated molecules, bulk solids, and material interfaces, including surfaces.
In this lecture the basic theoretical concepts underlying DFT calculations are introduced.
Practical applications of DFT, focusing on planewave DFT, are discussed and hands-on training is provided using the open-source code ABINIT.
The course is a practical introduction for students of materials science, physics and chemistry who want to use DFT in their work.

- Short repetition of Quantum Mechanics (infinitely deep well, harmonic oscillator, H atom, Hartree-Fock approximation for interacting systems)
- Basic concepts in DFT (Hohenberg-Kohn theorems, Kohn-Sham ansatz, local-density approximation)
- Functioning of DFT planewave pseudopotential codes
- Tools for electronic-structure analysis (density, density of states, Bader charge analysis, band structure)
- Calculating bulk properties
- Calculating defect (free) energies (surfaces, interfaces, point defects)
- Calculating kinetic energy barriers (nudged-elastic-band method)
- Modeling complex structure: ab initio molecular dynamics, simulated annealing, basin hopping and other structure search techniques.
- Density-functional perturbation theory: application to phonon band-structures
- Improved band-structure methods: LDA+U, hybrid functionals and the GW method.

Learning Outcomes, Qualification, and Competence Aims
After successfully completing this course, the student will be in the position to independently run DFT calculations using the ABINIT code and the PYTHON based Atomic Simulation Environment package. Specifically he/she will learn how to compute bulk elastic properties, surface/interface/defect (free) energies, electron and phonon band-structures and transition barriers for chemical reactions. In addition, the student will learn how to use density-of-states, electron densities and Kohn-Sham orbitals as tools for electronic-structure analysis. Finally, he/she will be introduced to basic concepts of DFT (Hohenberg-Kohn theorems, Kohn-Sham ansatz, local density approximation of the exchange-correlation functional) and of the functioning of planewave-pseudopotential codes.

Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Course

Prerequisites	**Literature***
Background in materials science, physics or chemistry on the bachelor level.	1. D. Sholl, J. A. Steckel, "Density Functional Theory: A Practical Introduction", Wiley 2009 2. http://www.abinit.org

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Magnetism and Magnetic Materials

responsible: **Prof. Dr. L. Alff**

Course [M.MMM] Magnetism and Magnetic Materials	**Module** Materials Science Advanced Elective Courses	**Instructor(s)** L. Alff, W. Donner
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered Every WS	**Recommended Semester*** 1st or 3rd Semester	**Weekday/Time/Place*** see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Basic notions of magnetism
- Magnetism in atoms and ions
- Magnetism in metallic materials
- Crystal field symmetry and Exchange Interaction
- Magnetically ordered structures
- Magnetic order, symmetry and phase transitions
- Micromagnetism and domain behavior
- Experimental methods in magnetism
- Selected (hot) topics from current research

Learning Outcomes, Qualification, and Competence Aims
The student is able to remember the basic notions of magnetism for a broad range of situations and materials. The student has the competence to differentiate different types of magnetism and their origin, and to correlate them with materials properties. He/she is qualified to evaluate experimental and theoretical methods for goal-oriented research in the area of magnetism and magnetic materials. The student remembers modern magnetic materials and their use in current applications. The student has a first insight in modern research in magnetism and magnetic materials and a beginner's competence to follow advanced textbooks and scientific literature.

Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Course

Prerequisites
Quantum Mechanics for Materials Science recommended

Literature*

1. S. Blundell: *Magnetism in Condensed Matter*, Oxford University Press (2001)
2. J. M.D. Coey: *Magnetism and Magnetic Materials*, Cambridge University Press (2009)
3. D. Jiles: *Introduction to Magnetism and Magnetic Materials*, Chapman & Hall (2001)
4. R. Skomski: *Simple Models of Magnetism*, Oxford University Press (2008)
5. N. Spaldin, *Magnetic Materials*, Cambridge University Press (2006)
6. L. Alff, *Magnetismus und magnetische Materialien*, Lecture notes (2004)

Form of Examination* oral	**Length of Examination*** 30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Spintronics

responsible: **Prof. Dr. L. Alff**

Course	**Module**	**Instructor(s)**
[M.SPT] Spintronics	Materials Science Advanced Elective Courses	L. Alff, W. Donner
Form of Teaching / Credit Hours	**Credit Points**	**Language**
L/2	3	English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every SS	2nd Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Introduction and basic notions of spintronics
- Spin dependent transport
- Magneto resistive (MR) effects, anisotropic magneto resistance (AMR)
- Giant magneto resistance (GMR)
- Spin dependent tunneling and tunneling magneto resistance (TMR)
- Materials for Spintronics, colossal magneto resistance (CMR)
- Spin transport in semiconductors
- Spintronic devices
- Meso and nanomagnetism
- Magnetic storage
- Selected (hot) topics from current research

Learning Outcomes, Qualification, and Competence Aims
The student is able to adapt the concepts of spintronics to a broad range of situations and materials. The student has the competence to differentiate different types of magneto-resistive effects and their origin, and to correlate them with materials properties. He/she is qualified to evaluate experimental and theoretical methods for goal-oriented research in the area of spintronics. The student remembers modern spintronic materials and their use in current applications. The student has a first insight into modern research in spintronics and its device applications. He/she has a beginner's competence to follow advanced textbooks and scientific literature.

Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Courses

Prerequisites
Quantum Mechanics for Materials Science and Magnetism and Magnetic Materials recommended

Literature*

1. M. Ziese, M. J. Thornton (Eds.), *Spin Electronics*, Springer (2001)
2. D. D. Awschalom et al. (Eds.), Spin Electronics, Kluwer (2004)
3. S. Maekawa, *Spin Electronics,* Oxford University Press (2006)
4. S. Bandyopadhyay and M. Cahay, *Introduction to Spintronics*, Crc Pr Inc (2008)
5. L. Alff, *Spintronics*, Lecture Material (latest version 2010)

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Advanced Materials

responsible: **Prof. Dr. L. Alff**

Course	**Module**	**Instructor(s)**
[M.AM] Advanced Materials	Materials Science Advanced Elective Courses	L. Alff, J. Kurian
Form of Teaching / Credit Hours	**Credit Points**	**Language**
L/2	3	English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every SS	2nd Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Introduction to modern materials and challenges in the field
- Theoretical methods
- Dielectrics, high-*k* materials
- Magnetic materials and materials for spintronics
- Superconductivity and superconducting materials for applications
- Carbon nanotubes
- Biocompatible materials
- Selected energy materials
- Selected (hot) topics from current research

Learning Outcomes, Qualification, and Competence Aims
The student has gained a broad overview on functional materials and the material's challenges of the 21. Century. The student has the competence to differentiate different types of materials and the physical origins of the desired functions. He/she is qualified to evaluate experimental and theoretical methods for goal-oriented research in the area of modern materials. The student has a first overview about the applications of modern materials in devices. The student has a first insight in modern research in novel materials. He/she has a beginner's competence to follow advanced textbooks and scientific literature. In particular, the student uses web resources in scientific literature to gain the desired level of information needed.

Annotations / Usability of Module*
M.Sc. Materials Science: Elective Course

Prerequisites	**Literature***
none	1. L. Alff and J. Kurian, *Advanced Materials*, Lecture material (latest version 2010) 2. Due to the diversity of the topics, no selfcontained textbooks are available. It is one important learning outcome of this course, to be able to find suited reviews in the scientific literature that gives an introduction to each material's class on the desired level.

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Materials Science of Thin Films
responsible: **Prof. Dr. L. Alff**

<table>
<tr><td colspan="2">Course
[M.TF] Materials Science of Thin Films</td><td colspan="2">Module
Materials Science Advanced Elective Courses</td><td colspan="2">Instructor(s)
L. Alff, W. Jaegermann, A. Klein, T. Mayer, P. Komissinskiy</td></tr>
<tr><td colspan="2">Form of Teaching / Credit Hours
L/2</td><td colspan="2">Credit Points
3</td><td colspan="2">Language
English</td></tr>
<tr><td colspan="6">Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h</td></tr>
<tr><td>Module Offered
Every SS</td><td colspan="3">Recommended Semester*
2nd Semester</td><td colspan="2">Weekday/Time/Place*
see University Catalog</td></tr>
<tr><td colspan="6">Examination Requirements
Graded Examination</td></tr>
<tr><td colspan="6">Content of Teaching and Examination
Introduction to thin film technology
Nucleation: Thermodynamics and kinetics
Structure and strain
Thermal Evaporation
Sputtering
Chemical vapor deposition (CVD)
Molecular beam epitaxy (MBE)
Pulsed laser deposition (PLD)
Thin film deposition of oxides
Thin films for solar cells</td></tr>
<tr><td colspan="6">Learning Outcomes, Qualification, and Competence Aims
The student has gained a broad overview on and remembers relevant thin film deposition methods. He/she is able to identify the advantages and disadvantages of each deposition method for different applications and needs. The student has the competence to apply fundamental thin film science to novel materials. The student has the competence to differentiate different types of deposition methods according to their physical and chemical principles. He/she is qualified to evaluate thin film methods for goal-oriented research in the diverse fields of thin film applications. The student has a first insight in modern research in thin films and a beginner’s competence to follow advanced textbooks and scientific literature.</td></tr>
<tr><td colspan="6">Annotations / Usability of Module*
M.Sc. Materials Science: Elective Course</td></tr>
<tr><td>Prerequisites
none</td><td colspan="5">Literature*
M. Ohring: Materials Science of Thin Films, Academic Press (2002)
L. B. Freund and S. Suresh: Thin Film Materialss, Cambridge University Press (2003).
R. Eason (Ed.): Pulsed Laser Deposition of Thin Films, Wiley (2007)
17. IFF-Ferienkurs: Dünne Schichten und Schichtsysteme, Forschungszentrum Jülich (1986)</td></tr>
<tr><td colspan="3">Form of Examination*
oral</td><td colspan="3">Length of Examination*
30 min</td></tr>
<tr><td colspan="6">Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.</td></tr>
</table>

* optional information

Characterization Methods of Materials Science – Neutrons and Synchrotron

responsible: **Prof. Dr. W. Donner**

Course [M.MNS] Characterization Methods of Materials Science – Neutrons and Synchrotron	**Module** Materials Science Advanced Elective Courses	**Instructor(s)** W. Donner
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English
Expenditure of Work Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h; Sum: 90 h		
Module Offered Every SS	**Recommended Semester*** 2nd Semester	**Weekday/Time/Place*** see University Catalog
Examination Requirements Graded Examination		
Content of Teaching and Examination • Synchrotron and Neutron Sources • Neutron Reflectivity • Crystal Truncation Rod Diffraction • Diffuse Scattering • Inelastic Scattering • Quasi-elastic Scattering • Coherent Diffraction and Reconstruction • Selected topics from current research		
Learning Outcomes, Qualification, and Competence Aims The students learn about the technology and possibilities of large research facilities. They are able to relate the specific advantages of Neutron and Synchrotron sources over conventional lab-based radiation sources to modern analytical methods. The course enables the students to associate specific problems in Materials Science to analytical techniques that are available at large scale facilities. The students are qualified to design specific experiments at Neutron and Synchrotron sources and evaluate the resulting data. They acquired a competence to critically evaluate the outcome of large scale experiments and to comment on results presented in the literature.		
Annotations / Usability of Module* M.Sc. Materials Science Advanced Elective Courses		
Prerequisites Advanced methods lecture and laboratory recommended	**Literature*** 1. Elements of Modern X-ray Physics, Als-Nielsen & McMorrow 2. Diffuse X-ray Scattering and Models of Disorder, Welberry 3. Diffuse X-ray Scattering from Crystalline Materials, Nield & Keen	
Form of Examination* oral	**Length of Examination*** 30 min	
Grade Composition* 100% oral exam. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.		

* optional information

Mass Spectrometry

responsible: **Prof. Dr. W. Ensinger**

Course [M.MS] Mass Spectrometry	**Module** Materials Science Advanced Elective Courses	**Instructor(s)** W. Ensinger, S. Flege
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English
Expenditure of Work Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h		
Module Offered Every SS	**Recommended Semester*** 2nd Semester	**Weekday/Time/Place*** see University Catalog
Examination Requirements Graded Examination		
Content of Teaching and Examination • Ionization processes • Desorption processes of liquids and solids • Technical realization (sample introduction, ionization methods, mass analyzers, detectors, coupling of separation devices) • Mass spectral interpretation, isotopic distribution • Applications		
Learning Outcomes, Qualification, and Competence Aims The student has gained an overview of mass spectrometric techniques, for both organic and inorganic samples. He/she is qualified to select the appropriate technique depending on the purpose of the investigation. The student is able to interpret mass spectra and can differentiate between effects occurring in the different parts of a mass spectrometer that influence the mass spectrum. He/she is aware of the factors limiting the spatial resolution in the analysis of solids. The student obtained the competence to follow advanced literature in the field of mass spectrometry.		
Annotations / Usability of Module* M.Sc. Materials Science: Elective Course		
Prerequisites none	**Literature*** 1. J.H. Gross *Mass Spectrometry*, Springer (2004) 2. J.S. Becker *Inorganic Mass Spectrometry-Principles and Applications*, Wiley (2007) 3. J.T. Watson, O.D. Sparkman *Introduction to Mass Spectrometry*, Wiley (2007) 4. E. de Hoffmann, V. Stroobant *Mass Spectrometry – Principles and Applications*, Wiley (2007)	
Form of Examination* oral	**Length of Examination*** 30 min	
Grade Composition* 100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.		

* optional information

Properties of Ferroelectric Materials

responsible: **Dr. W. Jo**

Course	**Module**	**Instructor(s)**
[M.FEM] Properties of Ferroelectric Materials	Materials Science Advanced Elective Courses	J. Rödel, W. Jo
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every SS	2nd Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Polarization mechanisms in gases, liquids and solids
- Symmetry-property relations in polar materials: Piezo-, pyro- & ferroelectricity
- Landau theory of phase transitions
- Domain structure of uni- and polyaxial ferroelectrics
- Coupling of ferroelectric & ferroelastic behavior
- Domain reversal & ferroelectric hysteresis
- Domain walls, small-signal behavior, Rayleigh law
- Preisach modelling
- Damage mechanisms, aging & fatigue
- Technically relevant ferroelectrics
- Special cases: Antiferroelectrics, relaxors, multiferroics...
- Further applications of ferroelectric materials

Learning Outcomes, Qualification, and Competence Aims
The student can identify different mechanisms of electrical polarization and is able to deduce possible polarization effects from information about the structure of a material. He/she can chose basic characterization techniques and adapt them to the requirements of a given problem. The student understands the influence of domain structures on the properties of a ferroelectric/ferroelastic and knows how to manipulate these structures to obtain optimum material response for a specific application. He/she has the competence to devise methods of optimizing existing ferroelectric materials and to develop new materials with improved properties. The student has a first insight in modern research in ferroelectrics and is competent to follow advanced textbooks and scientific literature.

Annotations / Usability of Module*
M.Sc. Materials Science: Elective Course

Prerequisites
none

Literature*

1. S. Sonin and B. A. Strukow: *Einführung in die Ferroelektrizität*, Vieweg Verlag (1982)
2. R. E Newnham: *Properties of materials – Anisotropy / Symmetry / Strcuture*, Oxford University Press (2005).
3. B Jaffe, W. R. Cook, and H. Jaffe: *Piezoelectric ceramics*, Academic Press (1971)
4. M. E. Lines and A. M. Glass: *Prinicples and applications of ferroelectrics and related materials*, Oxford University Press (1977)

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Mechanical Properties of Ceramic Materials

responsible: **Dr. K. Webber**

<table>
<tr><td colspan="2">Course
[M.MPCM] Mechanical Properties of Ceramic Materials</td><td colspan="2">Module
Materials Science Advanced Elective Courses</td><td colspan="2">Instructor(s)
J. Rödel, K. Webber</td></tr>
<tr><td colspan="2">Form of Teaching / Credit Hours
L/2</td><td colspan="2">Credit Points
3</td><td colspan="2">Language
English</td></tr>
<tr><td colspan="6">Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h</td></tr>
<tr><td>Module Offered
Every WS</td><td colspan="2">Recommended Semester*
1st or 3rd Semester</td><td colspan="3">Weekday/Time/Place*
see University Catalog</td></tr>
<tr><td colspan="6">Examination Requirements
Graded Examination</td></tr>
<tr><td colspan="6">Content of Teaching and Examination
• Overview of technical ceramics in relation to their mechanical properties
• Stress intensity factor, mechanical energy release rate, instability criterion
• Fracture strength, fractography
• Crack tip toughness, crack shielding, theory of R-curves
• Process zone mechanisms: phase transformation, microcracking, ferroelasticity
• Fiber reinforcement, micromechanics of whiskers and particle toughening
• Mechanics of laminates
• Subcritical crack growth and fatigue, life time predictions
• Creep, sintering
• Thermal shock, hardness and wear
• Measurement methodology, Weibull’s law</td></tr>
<tr><td colspan="6">Learning Outcomes, Qualification, and Competence Aims
The student has obtained a global and detailed view of the different mechanical properties of ceramic materials, composites and structures. This knowledge allows him/her to choose materials with adequate properties for a given application. The student understands the phenomenon responsible for crack extension and brittle fracture under the combined effects of applied loading, temperature, time, chemical environment. He/she can choose appropriate measurement techniques to get reliable data. The student understands the influence of microstructure on the mechanical properties of ceramic materials. He/she has the competence to devise mechanisms of optimizing existing ceramic materials and to develop new materials with improved properties. The student has a first insight into modern research in the field of mechanics of ceramics and is competent to follow advanced textbooks and scientific literature.</td></tr>
<tr><td colspan="6">Annotations / Usability of Module*
M.Sc. Materials Science: Elective Course</td></tr>
<tr><td>Prerequisites
none</td><td colspan="5">Literature*
1. B. Lawn: Fracture of Brittle Solids – 2nd Edition, Cambridge University Press (1993)
2. D. Munz, T. Fett: Ceramics - Mechanical properties, failure behaviour, materials selection, Springer Verlag Berlin Heidelberg (1999)
3. D.J. Green: An introduction to mechanical properties of ceramics, Cambridge University Press (1998)</td></tr>
<tr><td colspan="3">Form of Examination*
oral</td><td colspan="3">Length of Examination*
30 min</td></tr>
<tr><td colspan="6">Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.</td></tr>
</table>

* optional information

Electrochemistry in Energy Applications I: Converter Devices

responsible: **Prof. Dr. W. Jaegermann, PD Dr. B. Kaiser, Dr. Th. Mayer, Dr. R. Hausbrand**

<table>
<tr><td colspan="2">Course
[M.MSS] Electrochemistry in Energy Applications I: Converter Devices</td><td colspan="2">Module
Materials Science Advanced Elective Courses</td><td>Instructor(s)
W. Jaegermann, Th. Mayer, B. Kaiser, R. Hausbrand</td></tr>
<tr><td colspan="2">Form of Teaching / Credit Hours
L/2</td><td colspan="2">Credit Points
3</td><td>Language
English</td></tr>
<tr><td colspan="5">Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h; Sum: 90 h</td></tr>
<tr><td>Module Offered
Every WS</td><td colspan="2">Recommended Semester*
1st or 3rd Semester</td><td colspan="2">Weekday/Time/Place*
see University Catalog</td></tr>
<tr><td colspan="5">Examination Requirements
B. S. Examination</td></tr>
<tr><td colspan="5">Content of Teaching and Examination
Electrochemical Thermodynamics
Electrochemical Kinetics
Electrochemical Methods
Fuel cells
Electrolysis</td></tr>
<tr><td colspan="5">Learning Outcomes, Qualification, and Competence Aims
The student will be introduced to the main concepts of heterogeneous electrochemistry (electrodics), basic electrochemical methods and main materials science questions related to the use and application of electrochemical converter devices. She/He will learn to evaluate experimental and theoretical results obtained with different electrochemical, surface science and theoretical techniques, and obtain a first insight in modern electrodics applied for continuing experimental work in this field. Moreover, he/she obtains basic competence to follow advanced textbooks and scientific literature.</td></tr>
<tr><td colspan="5">Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Courses</td></tr>
<tr><td>Prerequisites
course on surface and interface properties; Quantum Mechanics for Materials Science recommended</td><td colspan="4">Literature*
G. Wedler; Lehrbuch der Physikalischen Chemie
P.W. Atkins; Physikalische Chemie (Physical Chemistry)
C.H. Hamann, W. Vielstich; Elektrochemie (Electrochemistry)
W. Schmickler; Grundlagen der Elektrochemie
W. Vielstich, A. Lamm, H. Gasteiger (eds); Handbook of Fuel Cells: Fundamentals, Technology, Application
G. Hoogers (ed.); Fuel Cell Technology Handbook</td></tr>
<tr><td colspan="3">Form of Examination*
oral</td><td colspan="2">Length of Examination*
30 min</td></tr>
<tr><td colspan="5">Grade Composition*
100% oral exam. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.</td></tr>
</table>

* optional information

Electrochemistry in Energy Applications II: Storage Devices

responsible: **Prof. Dr. W. Jaegermann, PD Dr. B. Kaiser, Dr. Th. Mayer, Dr. R. Hausbrand**

Course	**Module**	**Instructor(s)**
[M.MSS] Electrochemistry in Energy Applications II: Storage Devices	Materials Science Advanced Elective Courses	W. Jaegermann, Th. Mayer, B. Kaiser, R. Hausbrand
Form of Teaching / Credit Hours	**Credit Points**	**Language**
L/2	3	English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h; Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every SS	1st or 3rd Semester	see University Catalog

Examination Requirements
B. S. Examination

Content of Teaching and Examination

- Solid State Ionics
- Battery Fundamentals
- Li-Ion Batteries
- Semiconductor Electrochemistry
- Electrochemical Solar Cell
- Photocatalysis
- Photoelectrochemical Hydrogen Production

Learning Outcomes, Qualification, and Competence Aims
The student will be introduced to the main concepts of heterogeneous electrochemistry (electrodics), solid state ionics and main materials science questions related to the use and application of electrochemical storage and converter devices. She/He will learn to combine electrochemical concepts and solid state concepts for dealing with energy devices and to evaluate experimental and theoretical results obtained with different electrochemical, surface science and theoretical techniques, and obtain a first insight in modern electrodics applied for continuing experimental work in this field. Moreover, he/she obtains basic competence to follow advanced textbooks and scientific literature.

Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Courses

Prerequisites	**Literature* Literature***
course on surface and interface properties; Quantum Mechanics for Materials Science recommended ; first part of the course recommended	G. Wedler; *Lehrbuch der Physikalischen Chemie* C.H. Hamann, W. Vielstich; *Elektrochemie (Electrochemistry)* J. Maier, *Physical Chemistry of Ionic Materials* Thomas B. Reddy, David Linden, *Handbook of batteries* Robert A. Huggins , *Advanced Batteries, Materials Science Aspects* M. Wakihara, O. Yamamoto (eds.), *Lithium Ion Batteries, Fundamentals and Performance* R. Memming; *Semiconductor Electrochemistry* C.A. Grimes, O.K. Varghese, S. Ranjan; *Light, Water, Hydrogen*

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral exam. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Fundamentals and Techniques of Modern Surface Science

responsible: **Prof. Dr. W. Jaegermann, Prof. Dr. A. Klein, Dr. T. Mayer, PD Dr. B. Kaiser**

Course	**Module**	**Instructor(s)**
[M.MSS] Fundamentals and Techniques of Modern Surface Science	Materials Science Advanced Elective Courses	W. Jaegermann, A. Klein, T. Mayer, B. Kaiser
Form of Teaching / Credit Hours	**Credit Points**	**Language**
L/2	3	English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h; Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every WS	1st or 3rd Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Vacuum techniques
- Auger-electron spectroscopy (AES)
- X-ray photoelectron spectroscopy (XPS)
- Ultraviolett photoelectron spectroscopy (UPS)
- Inverse photoemission spectroscopy (IPE, BIS)
- Electron energy loss spectroscopy (ELS,HREELS)
- X-ray absorption spectroscopy (XAS, NEXAFS)
- Thermal desorption spectroscopy (TDS)
- High energy electron diffraction (LEED)
- Ion scattering (ISS, LEISS)}
- Scanning tunneling microscopy (STM)
- Atomic force microscopy (AFM)

Learning Outcomes, Qualification, and Competence Aims
The student has been introduced to the main methods used in modern surface science, he/she is familiar with the basic physical processes used for the different techniques, he/she has learned for which problems and how the techniques are applied in surface science, she/he has been introduced to the main materials science questions related to the use and application of these techniques, the student has the competence to judge when the application of these techniques is of use in his/her future scientific life, he/she is qualified to evaluate experimental and theoretical results obtained with these techniques, the student has obtained a first insight in modern surface science research and techniques applied for continuing experimental work in this field, he/she has obtained basic competence to follow advanced textbooks and scientific literature.

Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Courses

Prerequisites
Quantum Mechanics for Materials Science recommended; basic knowledge of surface and interface science

Literature*

1. W.Mönch: Semiconductor Surfaces and Interfaces (Springer, 2001)
2. G.Ertl, J.Küppers: Low Energy Electrons and Surface Chemistry (VCH, 1974)
3. M.A.van Hove, S.Y.Tong: Surface Crystallography by LEED (Springer, 1979)
4. D.P.Woodruff, T.A.Delchar: Modern Techniques in Surface Science (Cambridge University Press, 1986)
5. D.Briggs, M.P.Seah: Practical Surface Analysis (Wiley, 1996)
6. St.Hüfner: Photoelectron Spectroscopy (Springer, 1994)
7. M.Cardona, L.Ley: Photoemission in Solids I + II (Springer)
8. M.Grasserbauer, H.J.Dudek, M.F.Ebel: Angewandte Oberflächenanalyse (Springer, 1986)
9. C.D.Wagner, W.M.Riggs, L.E.Davis, J.F.Moulder, G.E.Muilenberg: Handbook of X-ray Photoelectron Spectroscopy (Perkin-Elmer 1979)
10. C.S.Fadley: The Study of Surface Structures by Photoelectron Diffraction and Auger Electron Diffraction (Synchrotron Radiation Research: Advancesin Surface and Interface Science, Vol 1: Techniques, Plenum Press, 1992)
11. H.-J.Güntherodt, R.Wiesendanger: Scanning Tunneling Microscopy I-III (Springer, 1994)
12. J.T.Yates: Experimental Innovations in Surface Science (Springer, 1997)

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral exam. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Fundamentals and Technology of Solar Cells

responsible: **Prof. Dr. W. Jaegermann**

<table>
<tr><td colspan="2">Course
[M.SC] Fundamentals and Technology of Solar Cells</td><td colspan="2">Module
Materials Science Advanced Elective Courses</td><td colspan="2">Instructor(s)
W. Jaegermann</td></tr>
<tr><td colspan="2">Form of Teaching / Credit Hours
L/2</td><td colspan="2">Credit Points
3</td><td colspan="2">Language
English</td></tr>
<tr><td colspan="6">Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h; Sum: 90 h</td></tr>
<tr><td>Module Offered
Every SS</td><td colspan="3">Recommended Semester*
2nd Semester</td><td colspan="2">Weekday/Time/Place*
see University Catalog</td></tr>
<tr><td colspan="6">Examination Requirements
Graded Examination</td></tr>
<tr><td colspan="6">Content of Teaching and Examination
energy resources and scenarios
fundamentals of semiconductor and device physics
preparation and properties of single crystalline Si cells, compound semiconductor cells, high performance cells, thin film solar cells</td></tr>
<tr><td colspan="6">Learning Outcomes, Qualification, and Competence Aims
The student has gained the information to address and judge energy topics in their relevance for future technology areas, he/she has gained a broad understanding of semiconductor physics as background of the working principles of solar cells, he/she has been introduced to the materials science challenges given for the different cell technologies, he/she has learned which preparation and processing techniques are involved in the manufacturing and improvement of solar cells, he/she is qualified to evaluate experimental and theoretical methods for possible future research in solar cell basic science and technology, he/she has obtained the competence to follow advanced textbooks and scientific literature.</td></tr>
<tr><td colspan="6">Annotations / Usability of Module*
M.Sc. Materials Science: Elective Course</td></tr>
<tr><td>Prerequisites
none</td><td colspan="5">Literature*
W. Jaegermann, Solar Cells, Lecture material (latest version 2010)
Basic Semiconductor Physics Books e.g. Sze, Semiconductor Physics
Different specialized books and reviews on solar cells, to be announced</td></tr>
<tr><td colspan="3">Form of Examination*
oral</td><td colspan="3">Length of Examination*
30 min</td></tr>
<tr><td colspan="6">Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.</td></tr>
</table>

* optional information

Transmission Electron Microscopy (TEM)

responsible: **Prof. Dr. H.-J. Kleebe, Dr. S. Lauterbach**

Course	**Module**	**Instructor(s)**
[M.TEMS] Transmission Electron Microscopy (TEM)	Materials Science Advanced Elective Courses	H.-J. Kleebe, S. Lauterbach
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h; Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every WS	1st or 3rd Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Conventional Transmission Electron Microscopy (TEM)
- Specimen Preparation
- Elements of the TEM (e.g., Lenses, Lens Aberrations)
- Electron Diffraction
- Bright Field and Dark Field Imaging Techniques
- Defects in Solids
- High-Resolution TEM
- Novel Developments in TEM (e.g., Cs- and Cc-Correctors)

Learning Outcomes, Qualification, and Competence Aims
The student will be introduced to the operation of a modern transmission electron microscope (TEM), he/she will be familiar with the basic physical principals of TEM, he/she will be able to judge where this technique can be utilized and which limitations come with it, he/she will be introduced to a number of practical applications of TEM in material science and will be competent to evaluate experimental results obtained with this technique, the student will have obtained first insights in modern transmission electron microscopy and will be able to independently apply this knowledge for the continuation of her/his own experimental research in this area.

Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Courses

Prerequisites
Introduction to Scanning Electron Microscopy recommended

Literature*

1. Transmission Electron Microscopy, D.B. Williams and C.B. Carter, (2nd Ed.) Springer Verlag (2009)
2. Introduction to Conventional Transmission Electron Microscopy, M. De Graef, Cambridge University Press (2003)
3. Principles of Analytical Electron Microscopy, J. Goldstein, D. C. Joy (Editor), A. D. Romig Jr., Springer Verlag (1986)
4. Electron Diffraction in the Electron Microscope, J.W. Edington, Macmillan (1975)
5. Electron Microdiffraction, J. C. H. Spence and J. M. Zuo, Springer Verlag, Berlin (1992)
6. Electron Beam Analysis of Materials, M. H. Loretto (2nd Ed.) Chapman & Hall (1994)
7. Electron Microscopy of Thin Crystals, P. B. Hirsch, A. Howie, R. B. Nicholson, D. W. Pashley and M. J. Whelan, Butterworths London (1965)
8. Physical Principles of Electron Microscopy: An Introduction to TEM, SEM, and AEM, R. Egerton, Springer Verlag (2005)
9. Transmission Electron Microscopy: Physics of Image Formation and Microanalysis, L. Reimer, Springer New York (2009)
10. High-Resolution Transmission Electron Microscopy and Associated Techniques, P. Buseck, J. Cowley, L. Eyring, Oxford University Press (1988)
11. High-Resolution Electron Microscopy, J. C. H. Spence, Oxford University Press (2009)

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral exam. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Semiconductor Interfaces

responsible: **Prof. Dr. A. Klein**

Course [M.SCI] Semiconductor Interfaces	**Module** Materials Science Advanced Elective Courses	**Instructor(s)** A. Klein
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English
Expenditure of Work Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h		
Module Offered Every WS	**Recommended Semester*** 1st or 3rd Semester	**Weekday/Time/Place*** see University Catalog
Examination Requirements Graded Examination		
Content of Teaching and Examination • Carrier concentrations in semiconductors • Excess carriers and carrier recombination • Space charge layers • Schottky diodes and p/n-junctions • Charge transport characteristics of semiconductor diodes • Solar cells, light emitting diodes, semiconductor lasers • Barrier formation at semiconductor interfaces		
Learning Outcomes, Qualification, and Competence Aims The student is able to remember the basic notions of semiconductor physics including carrier concentrations in thermal equilibrium and non-equilibrium situations. The student has the competence to develop energy band diagrams and understand the function of all basic semiconductor structures. He/she is qualified to evaluate semiconductor devices and remembers most important semiconductor materials, their properties and their use in current applications. The student is aware of several materials limitations of semiconductor devices.		
Annotations / Usability of Module* M.Sc. Materials Science Advanced Elective Course		
Prerequisites Introduction to Solid State Physics recommended	**Literature*** 1. Klein, *Semiconductor Interface*, Lecture Notes (2009) 2. S.M. Sze, and K.K. Ng: *Physics of Semiconductor Devices*, John Wiley & Sons, Hoboken (2007) 3. P.Y. Yu, and M. Cardona: *Fundamentals of Semiconductors. Physics and Materials Properties*, Springer, Berlin (2001)	
Form of Examination* oral	**Length of Examination*** 30 min	
Grade Composition* 100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.		

* optional information

Thermodynamics and Kinetics of Defects

responsible: **Prof. Dr. A. Klein**

Course [M.TKD] Thermodynamics and Kinetics of Defects	**Module** Materials Science Advanced Elective Courses	**Instructor(s)** A. Klein
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English
Expenditure of Work Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h		
Module Offered Every other SS	**Recommended Semester***	**Weekday/Time/Place*** see University Catalog
Examination Requirements Graded Examination		

Content of Teaching and Examination

- Basic thermodynamics of solids
- Thermodynamics of point defects
- Defect reactions and concentrations
- Kröger-Vink notation and Brouwer approximation
- Boundary layers: Mott-Schottky and Guy-Chapman profiles
- Diffusion processes
- Chemical, electrical- and electrochemical potential gradients
- Ambipolar diffusion and oxidation of metals

Learning Outcomes, Qualification, and Competence Aims

The student is able to remember the relevance of point defects for the electronic properties of materials. He/she has the competence to identify conditions under which point defects define material properties and to develop strategies how these can be modified. The student has a basic qualification to make materials selections for electronic and ionic applications.

Annotations / Usability of Module*

M.Sc. Materials Science Advanced Elective Courses

Prerequisites	**Literature***
None	1. Klein, *Thermodynamik und Kinetik von Punktdefekten*, Lecture Notes (2006) 2. M.W. Barsoum, Fundamentals of Ceramics, IOP Publishing (2003) 3. J. Maier, *Physical Chemistry of Ionic Materials,* Wiley (2004)

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*

100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Graphen and Carbon Nanotubes - from fundamentals to applications

responsible: **Prof. Dr. R. Krupke**

Course	**Module**	**Instructor(s)**
[M.GCN] Graphen and Carbon Nanotubes - from fundamentals to applications	Materials Science Advanced Elective Courses	R. Krupke
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every SS	2nd Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Synthesis of graphene and carbon nanotubes
- Structure – property correlation
- Electrical and optical properties
- Device fabrication
- Potential applications

Learning Outcomes, Qualification, and Competence Aims
The student has gained a basic knowledge in the fundamentals of graphene and carbon nanotubes. He/she is able to understand how the atomic structure of a carbon allotrope determines its properties. He/she is able to understand the electrical and optical properties of nanocarbons and its implications for future applications. He/she is qualified in characterisation techniques and device fabrication techniques. The student has the competence to follow scientific literature and the knowledge that is required to conduct research in the field.

Annotations / Usability of Module*
M.Sc. Materials Science: Elective Course

Prerequisites
None

Literature*

1. S. Reich, C. Thomsen, J. Mautzsch, *Carbon Nanotubes: Basic Concepts and Physical Properties*, WILEY-VCH, 2004.
2. A. Jorio, G. Dresselhaus, M. Dresselhaus (Eds.), *Carbon Nanotubes: Advanced Topics in the Synthesis, Structure, Properties and Applications*, Series: Topics in Applied Physics Vol 111, Springer, 2008.
3. S. Heinze, J. Tersoff, P. Avouris, *Carbon nanotube electronics and optoelectronics*, Materials Today Vol 9, Page 46-54, 2006.
4. P. Avouris, M. Freitag, V. Perebeinos, *Carbon-nanotube photonics and optoelectronics*, Nature Photonics Vol 2, Page 341-350, 2008.
5. F. Bonaccorso, A. Lombardo, T. Hasan, Z. Sun, L. Colombo, A. Ferrari, *Production and processing of graphene and 2d crystals*, MaterialsToday Vol15, Page 564-589, 2012.
6. F. Bonaccorso, Z. Sun, T. Hasan, A. Ferrari, *Graphene Photonics and Optoelectronics*, Nature Photonics Vol 4, Page 611-622, 2010.

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Engineering Microstructures – Processing, Characterization and Application
responsible: **Prof. Dr. C. Müller**

Course	**Module**	**Instructor(s)**
[M.EMPCA] Engineering Microstructures – Processing, Characterization and Application	Materials Science Advanced Elective Courses	E. Bruder, C. Müller
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every WS	2nd Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination
- Introduction (dislocations, subgrain structures, grain boundaries, phase boundaries)
- Microstructural analysis (microscopy and diffraction methods)
- Correlation between microstructure and mechanical properties
- Thermo-mechanical treatment (theory and processing)
- Recovery, recrystallization and grain growth
- Severe plastic deformation
- Microstructures for structural applications

Learning Outcomes, Qualification, and Competence Aims
The student gains an overview of the variety of methods for microstructural engineering of metals and alloys including their thermodynamic principles and applications. The student remembers the potential and limits of state-of-the-art methods for microstructural analysis and is able to assess the most qualified method(s) for specific issues. He/she is qualified to evaluate experimental and theoretical methods for goal-oriented research in the area microstructural engineering by annealing, thermo-mechanical treatment or severe plastic deformation. The student has a beginner's competence to follow advanced textbooks and scientific literature.

Annotations / Usability of Module*
M.Sc. Materials Science: Elective Course

Prerequisites	**Literature***
Bachelor modules “Real Crystals”and “Mechanical Properties” recommended	1. R.W. Cahn, P. Haasen: *Physical Metallurgy*, Elsevier Science B.V. (1996) 2. F.J. Humphreys, M. Hatherly: *Recrystallization and Related Annealing Phenomena*, Elsevier (2004) 3. G. Gottstein, *Physikalische Grundlagen der Materialkunde* (in German), Springer (2007)

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Mechanical Properties of Metals

responsible: **Prof. Dr. C. Müller**

<table>
<tr><td colspan="2">Course
[M.MPM] Mechanical Properties of Metals</td><td colspan="2">Module
Materials Science Advanced Elective Courses</td><td colspan="2">Instructor(s)
C. Müller</td></tr>
<tr><td colspan="2">Form of Teaching / Credit Hours
L/2</td><td colspan="2">Credit Points
3</td><td colspan="2">Language
English/German</td></tr>
<tr><td colspan="6">Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h</td></tr>
<tr><td>Module Offered
Every WS</td><td colspan="3">Recommended Semester*
1st or 3rd Semester</td><td colspan="2">Weekday/Time/Place*
see University Catalog</td></tr>
<tr><td colspan="6">Examination Requirements
Graded Examination</td></tr>
<tr><td colspan="6">Content of Teaching and Examination
• Microstructure – Property Relationship
• Tensile Testing
• Fracture Toughness
• Fatigue Life Time
• Fatigue Crack Propagation
• Crack Closure Effects
• Long Crack and Short Crack Behaviour</td></tr>
<tr><td colspan="6">Learning Outcomes, Qualification, and Competence Aims
The student is able to remember the basic notions of the behaviour of metallic materials under static and dynamic loading. He/she has the competence to differentiate the relevant mechanisms and their microstructural dependence. They are able to decide about the optimal microstructure for the prevailing mechanical loading and have basic knowledge about methods to produce the relevant microstructures. He/she is qualified to assess experimental and theoretical methods for goal-oriented research in the area of improving mechanical properties by microstructural optimization. The student has a beginner’s competence to follow advanced textbooks and scientific literature.</td></tr>
<tr><td colspan="6">Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Courses</td></tr>
<tr><td>Prerequisites
Mechanical behavior of materials recommended</td><td colspan="5">Literature*
1. Mechanical Behavior of Engineering Materials, J. Rösler, Springer Verlag
2. Materials Science and Engineering, R. W. Cahn et al. VCH-Verlag
3. Materials for Engineering, J. W. Martin. The Institute of Materials, London
4. Deformation and Fracture Mechanics of Engineering Materials, R.W. Hertzberg, John Wiley&Sons, Inc
5. Werkstoffkunde und Werkstoffprüfung, W. Domke. Verlag W. Girardet, Essen</td></tr>
<tr><td colspan="3">Form of Examination*
oral</td><td colspan="3">Length of Examination*
30 min</td></tr>
<tr><td colspan="6">Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.</td></tr>
</table>

* optional information

Modern Steels for Automotive Applications
responsible: **Prof. Dr. C. Müller**

Course [M.MSAA] Modern Steels for Automotive Applications	**Module** Materials Science Advanced Elective Courses	**Instructor(s)** C. Müller, T. Michler
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English
Expenditure of Work Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h		
Module Offered Every SS	**Recommended Semester*** 2nd Semester	**Weekday/Time/Place*** see University Catalog
Examination Requirements Graded Examination		
Content of Teaching and Examination • Production of steels • Thermomechanical treatments (TMT), microstructures, deformation and strengthening modes • Requirements for automotive applications • Modern high strength steels, TMT, microstructures, deformation and strengthening modes • High formability steels, TMT, microstructures, deformation and strengthening modes		
Learning Outcomes, Qualification, and Competence Aims The student has gained an advanced knowledge of the processing (TMT) of modern steels, their microstructures, their deformation and strengthening modes as well as their mechanical properties. He/she is able to correlate the mechanical properties with microstructural features and has an advanced knowledge of the methods to produce the required microstructure. The student has a first insight in the special requirements on steels/materials for automotive applications and a beginner's competence to follow advanced textbooks and scientific literature.		
Annotations / Usability of Module* M.Sc. Materials Science: Elective Course		
Prerequisites none	**Literature*** 7. F.B. Pickering „Physical Metallurgy and the design of steels“ Appl. Sci. Publ. 1978 8. D. Peckner and I.M. Bernstein “Handbook of stainless steels” McGraw-Hill 1977 9. F. Rapatz “Die Edelstähle” Springer 1962 (in German)	
Form of Examination* oral	**Length of Examination*** 30 min	
Grade Composition* 100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.		

* optional information

Superconductivity and Oxide Materials

responsible: **Prof. Dr. H. Rauh**

Course	**Module**	**Instructor(s)**
[M.SOM] Superconductivity and Oxide Materials	Materials Science Advanced Elective Courses	H. Rauh, L. Alff
Form of Teaching / Credit Hours	**Credit Points**	**Language**
L/2	3	English

Expenditure of Work
Lecture: 30 hrs, Homework: 30 hrs, Preparation for Examination: 30 hrs: Sum: 90 hrs

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
WS (not regularly)	1st or 3rd Semester	See University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- What constitutes superconductivity: electrical and magnetic key properties
- Brief historical introduction to superconductivity
- Classification: elemental superconductors, compounds, alloys, and high-T_c oxides
- Superconductor applications: high-current and high-field applications, electronic applications
- Charge transport: normal conducting state versus superconducting state, Cooper pair condensate
- Superconductivity as a macroscopic quantum phenomenon
- Meissner effect in bulk superconductors and thin superconducting films
- Quantization of magnetic flux
- Thermal properties: entropy and specific heat
- Phase diagrams, critical magnetic fields, and magnetization of ideal type-I and type-II superconductors
- Magnetic vortices in conventional and high-T_c superconductors
- Mixed state of type-II superconductors
- Magnetization and critical current density of real type-II superconductors
- Flow and pinning of magnetic flux
- Surface energy of type-I and type-II superconductors
- Concept of magnetic shielding to improve superconductor performance
- Josephson effects: current-phase and current-voltage relations, macroscopic quantum interference
- Oxide materials: crystal structure, physical properties, Lawrence-Doniach model of layered oxides
- Modelling of ceramic superconductors on mesoscopic and macroscopic scales

Learning Outcomes, Qualification, and Competence Aims
An open-minded, intelligent, and committed student should have a well-founded grasp of the basic phenomena of superconductivity and their significance for technological applications of superconducting materials, including the high-T_c oxides, at his, or her, disposal. Such a student should be endowed with a beginner's competence enabling him, or her, to follow advanced texts, and even original literature, on these materials and phenomena.

Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Course

Prerequisites
Basic knowledge in mathematics and solid state physics

Literature*

1. W. Buckel, R. Kleiner: *Supraleitung*, Wiley-VCH, Weinheim (2004)
2. M. Cyrot, D. Pavuna: *Introduction to Superconductivity and High-T_c Materials*, World Scientific, Singapore (1992)
3. C. Kittel: *Introduction to Solid State Physics*, Wiley, New York (2005)
4. T.P. Orlando, K.A. Delin: *Foundations of Applied Superconductivity*, Addison-Wesley, New York (1991)
5. V.V. Schmidt: *The Physics of Superconductors*, Springer, Berlin (1997)
6. J.R. Waldram: *Superconductivity of Metals and Cuprates*, IOP Publishing, Bristol (1996)

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Solid State Foundations of Materials Science (Electrons and Phonons)

responsible: **Prof. Dr. H. Rauh**

Course [M.SSEP] Solid State Foundations of Materials Science (Electrons and Phonons)		**Module** Materials Science Advanced Elective Courses	**Instructor(s)** H. Rauh, L. Alff
Form of Teaching / Credit Hours S/2		**Credit Points** 3	**Language** English
Expenditure of Work Seminar: 30 hrs, Homework: 30 hrs, Preparation for Examination: 30 hrs: Sum: 90 hrs			
Module Offered WS (not regularly)	**Recommended Semester*** 1st Semester		**Weekday/Time/Place*** See University Catalog
Examination Requirements Graded Examination			

Content of Teaching and Examination

- Classical model of free electrons:
  Electrical and thermal conductivity, Wiedemann-Franz law, heat capacity
- Quantum theoretical model of free electrons (Fundamentals):
  Schrödinger equation, eigenfunctions, eigenvalues, Pauli principle, density and occupancy of states, Fermi-Dirac distribution, Fermi surface
- Quantum theoretical model of free electrons (Applications I):
  Electrical and thermal conductivity, Wiedemann-Franz law, heat capacity
- Quantum theoretical model of free electrons (Applications II):
  Photoemission, thermionic emission, contact potential, cohesive energy, compressibility
- Energy bands:
  Nearly free electrons – Bragg reflections, charge distribution, energy dispersion;
  tightly bound electrons – parity, exchange interaction, energy dispersion;
  Schrödinger equation with a periodic potential – reduction to a system of algebraic equations, solution for weakly varying potential, effective mass, electrons and holes;
  definition of metals, semiconductors, and insulators based on electron theory
- Charge transport in semiconductors:
  Model of 'narrow' bands – electrical conductivity of intrinsic semiconductors, donor and acceptor states, electrical conductivity of extrinsic semiconductors;
  model of 'wide' bands – thermoluminescence, photoconductivity
- Lattice vibrations:
  Harmonic lattice with monatomic and diatomic basis – classical equations of motion, dispersion relations, acoustical and optical modes, long wavelength ('elastic') limit;
  quanta of elastic waves ('phonons'), density and occupancy of states, Planck distribution, Einstein and Debye models of heat capacity

Learning Outcomes, Qualification, and Competence Aims

An open-minded, intelligent, and committed student should have a well-founded grasp – and the faculty to convey the subjects – of crystal electrons and phonons as prototypes of elementary excitations in regularly structured solids at his, or her, disposal. Such a student should be endowed with a beginner's competence enabling him, or her, to follow advanced texts, and even original literature, on these excitations.

Annotations / Usability of Module*

M.Sc. Materials Science Advanced Elective Course

Prerequisites	**Literature***
Basic knowledge in mathematics and solid state physics	1. R.E. Hummel: *Electronic Properties of Materials*, Springer, Berlin (1993) 2. C. Kittel: *Introduction to Solid State Physics*, Wiley, New York (2005) 3. O. Madelung: *Introduction to Solid State Theory*, Springer, Berlin (1993) 4. A.P. Sutton: *Electronic Structure of Materials*, Clarendon Press, Oxford (1993) 5. S.V. Vonsovsky, M.I. Katsnelson: *Quantum Solid-State Physics*, Springer, Berlin (1989) 6. J.M. Ziman: *Principles of the Theory of Solids*, Cambridge University Press, Cambridge (1992)

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*

100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Solid State Foundations of Materials Science (Magnetism and Superconductivity)

responsible: **Prof. Dr. H. Rauh**

Course	**Module**	**Instructor(s)**
[M.SSMS] Solid State Foundations of Materials Science(Magnetism and Superconductivity)	Materials Science Advanced Elective Courses	H. Rauh, L. Alff
Form of Teaching / Credit Hours S/2	**Credit Points** 3	**Language** English

Expenditure of Work
Seminar: 30 hrs, Homework: 30 hrs, Preparation for Examination: 30 hrs: Sum: 90 hrs

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
SS (not regularly)	2nd Semester	See University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Magnetism of non-interacting electrons: Diamagnetism – classical model, magnetic susceptibility; quantum theoretical model, magnetic susceptibility; Paramagnetism – classical model, Langevin function, Curie's law; quantum theoretical model, Brillouin function, Curie's law, approximation for weak magnetic fields
- Ferromagnetism: Mean-field approximation, spontaneous magnetization, Curie-Weiss's law, temperature dependence of the reciprocal magnetic susceptibility and the saturation magnetization – behaviour near the Curie temperature and, respectively, absolute zero temperature
- Exchange interaction: Hydrogen molecule – Coulomb integral, exchange integral, generalization for many-spin systems, nearest-neighbour interactions, Heisenberg's Hamiltonian, direct exchange, superexchange
- Collective magnetic excitations: Spin waves in Heisenberg's model, dispersion relation, quanta of spin waves ('magnons'), thermal excitation of magnons – occupancy, magnetization, Bloch's $T^{3/2}$ law
- Superconductivity as a macroscopic quantum phenomenon: Phonon induced electron-electron interaction ('Cooper pairs') – correlations of momentum and spin, lowering of total energy; coherent ensemble of interacting Cooper pairs ('condensate') – condensate wave function, density of Cooper pairs, phase, current density-phase relation for a weak magnetic field
- Magnetic properties of superconductors: Meissner effect in a semi-infinite superconductor – magnetic induction and supercurrent density, temperature dependence of the penetration depth; quantization of magnetic flux; diamagnetism of ideal type-I and type-II superconductors, Meissner state and mixed state, magnetization, critical magnetic fields
- Josephson effects: Experimental observation, current-voltage characteristic of a Josephson junction, tunneling of Cooper pairs between weakly-coupled superconductors – current-phase and current-voltage relations, effect of a magnetic field, superconducting quantum interference

Learning Outcomes, Qualification, and Competence Aims
An open-minded, intelligent, and committed student should have a well-founded grasp – and the faculty to convey the subjects – of magnetism and superconductivity as prototypes of collective phenomena in regularly structured solids at his, or her, disposal. Such a student should be endowed with a beginner's competence enabling him, or her, to follow advanced texts, and even original literature, on these phenomena.

Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Course

Prerequisites
Basic knowledge in mathematics and solid state physics

Literature*

1. W. Buckel, R. Kleiner: *Supraleitung*, Wiley-VCH, Weinheim (2004)
2. C. Kittel: *Introduction to Solid State Physics*, Wiley, New York (2005)
3. H.P. Myers: *Introductory Solid State Physics*, Taylor & Francis, London (1991)
4. T.P. Orlando, K.A. Delin: *Foundations of Applied Superconductivity*, Addison-Wesley, New York (1991)
5. B.K. Tanner: *Introduction to the Physics of Electrons in Solids*, Cambridge University Press, Cambridge (1996)
6. J.M. Ziman: *Principles of the Theory of Solids*, Cambridge University Press, Cambridge (1992)

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Mathematical Methods in Materials Science

responsible: **PD Dr. Y. Genenko**

Course	**Module**	**Instructor(s)**
[M.TM] Mathematical Methods in Materials Science	Materials Science Advanced Elective Courses	Y. Genenko
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English

Expenditure of Work
Lecture: 30 hrs, Homework: 30 hrs, Preparation for Examination: 30 hrs: Sum: 90 hrs

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every WS	1st or 2nd Semester	See University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Linear ordinary differential equations: constant and variable coefficients
- Relaxation processes and oscillations in electrical circuits, parametric resonance
- Normal vibrational modes of polyatomic molecules: Lagrangian mechanics
- Linear partial differential equations: elliptic, hyperbolic, and parabolic equations
- Method of Fourier and Laplace transforms
- Diffusion in composite media: interface resistance
- Diffusion of foreign atoms to cylindrical and spherical precipitates
- Diffusion of magnetic field in a metal
- Solidification processes in an undercooled melt: Stefan problem
- Injection of electrons into dielectrics and organic semiconductors
- Green's function technique
- Bifurcations and phase transitions in open biological and chemical systems
- Self-organization in nonlinear active media

Learning Outcomes, Qualification, and Competence Aims
An open-minded, intelligent, and committed student should have a well-founded grasp of advanced mathematical techniques for exactly, or approximately, solving linear ordinary and partial differential equations, and their use for dealing with a variety of typical problems in materials science at his, or her, disposal. Such a student should be endowed with a competence enabling him, or her, to follow sophisticated texts on these techniques and even to address complex issues of that sort him-, or her-, self.

Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Course

Prerequisites
Basic knowledge in mathematics, physics, and materials science

Literature*

1. G.B. Arfken, H.J. Weber: *Mathematical Methods for Physicists*, Academic Press, New York (1995)
2. H.S. Carslaw, J.C. Jaeger: *Conduction of Heat in Solids*, Clarendon Press, Oxford (1993)
3. J. Crank: *The Mathematics of Diffusion*, Clarendon Press, Oxford (1994)
4. H. Heuser: *Gewöhnliche Differentialgleichungen – Einführung in Lehre und Gebrauch*, Teubner, Stuttgart (1995)
5. G. Lehner: *Elektromagnetische Feldtheorie für Ingenieure und Physiker*, Springer, Berlin (1996)
6. W. Richter: *Einführung in Theorie und Praxis der partiellen Differentialgleichungen*, Spektrum, Heidelberg (1995)

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Chemical Sensors: Basics and Applications

responsible: **PD Dr. A. Gurlo**

Course	**Module**	**Instructor(s)**
[M.CS] Chemical Sensors: Basics and Applications	Materials Science Advanced Elective Courses	A. Gurlo
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every SS	2nd Semester	see University Catalog

Examination Requirements

Graded Examination

Content of Teaching and Examination

- General introduction to the topic. Definitions: sensors, chemical sensors. Principle of construction (receptor and transducer). Gas sensors. Their importance (why, what for, application areas). Examples. Basic characteristics (response, signal, sensitivity).
- Classification (due to the transduction principles; materials; applications). Principle of detection. Physico-chemical processes responsible for the detection.
- Sensor fabrication. Micromachining. MEMS. CMOS. Deposition of sensing layers.
- Resistive sensors (chemoresistors). Semiconducting oxides (SnO2). Taguchi sensors. Microplatforms. Conducting polymers (phthalocyanine). Biomimicry.
- Capacitive sensors. Gas-sensitive polymers. Impedance spectroscopy. Humidity detectors.
- Electrochemical sensors. Ionic conductors. Lambda-sonde. Water vapour detection.
- Work function changes. Field-effect transistors. Hydrogen sensors.
- Thermochemical (calorimetric) sensors. Pellistors. Methane detection.
- Mass sensors. Quartz microbalance. Surface and bulk acoustic waves.
- Optical sensors. Non-dispersive IR. CO_2 sensors. Climate control systems in cars.
- Sensor arrays. Electronic noses. Data treatment. Multivariate analysis.

Learning Outcomes, Qualification, and Competence Aims

Research in the area of chemical and biochemical sensors and the development of respective applications is still growing rapidly. In the last decade it has become evident that the successful development of chemical and biochemical sensors resistant to the harsh conditions in the various routine applications calls for a cooperation between chemists and engineers. Thus, this course aims at instructing students in a strictly systematic, interdisciplinary and practice-oriented way about the basic technology of chemical sensors. This course bridges the gap between the different "ways of thinking" in chemistry, physics and engineering. It provides a firm grounding for advanced students who will gain a broad overview on chemical sensor technology in general and gas sensor technology in particular.

Annotations / Usability of Module*

M.Sc. Materials Science: Elective Course

Prerequisites	**Literature***
none	1. P. Gründler, Chemical Sensors: An Introduction for Scientists and Engineers // Chemische Sensoren. Eine Einführung für Naturwissenschaftler und Ingenieure, Springer, Berlin, 2004 (Deutsch)/2007 (English). 2. M. J. Madou, S. R. Morrison, Chemical Sensing with Solid State Devices, Academic Press, San Diego, 1989. 3. Chemical and Biochemical Sensors (Sensors: A Comprehensive Survey, Vol.2, Pt.1) (Eds.: W. Göpel, Jones, T.A., Kleitz, M., Lundström, J., Seiyama, T.), VCH, Weinheim, 1991.

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*

100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

High Pressure Materials Synthesis

responsible: **Prof. Dr. R. Riedel**

Course	**Module**	**Instructor(s)**
[M.HPMS] High Pressure Materials Synthesis	Materials Science Advanced Elective Courses	R. Riedel, D. Dzivenko
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every SS	2nd Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Pressure as a thermodynamic parameter; thermodynamics of deformation; equation of state
- Phase transitions and chemical reactions
- High-pressure apparatuses
- Chemistry at high pressures: synthesis of new materials

Learning Outcomes, Qualification, and Competence Aims
The student has gained a basic knowledge on high-pressure physics and materials synthesis techniques. He/she is able to identify the advantages and disadvantages of each HP preparative method for different applications and needs. He/she is qualified to evaluate high-pressure techniques for the synthesis of structural and functional materials with new dense structures. The student has a first insight in modern high-pressure research and a beginner's competence to follow advanced textbooks and scientific literature.

Annotations / Usability of Module*
M.Sc. Materials Science: Elective Course

Prerequisites
none

Literature*

10. N.W. Ashcroft, N.D. Mermin, *Festkörperphysik*, Oldenbourg, München, 2007.
11. C. Kittel, *Introduction to solid state physics*, J. Wiley & Sons, New York, 1986.
12. L.D. Landau, E.M. Lifshitz, *Course of Theoretical Physics, vol. 7: Theory of Elasticity*, Pergamon Press, London, 1975.
13. P.W. Atkins, *Physical Chemistry*, Oxford University Press, Oxford, 1998.
14. W.B. Holzapfel, N. S. Isaacs, *High-pressure Techniques in Chemistry and Physics*, Oxford University Press, Oxford, 1997.
15. M.I. Eremets, *High Pressure Experimental Methods*, Oxford University Press, Oxford, 1996.

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Materials Chemistry

responsible: **Prof. Dr. R. Riedel**

Course	**Module**	**Instructor(s)**
[M.MC] Materials Chemistry	Materials Science Advanced Elective Courses	R. Riedel
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every WS	1st or 3rd Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Introduction
- Silicon: Methods for the Preparation of High Purity Silicon
- Reaction in the Gas Phase: Mond-Process, van-Arkel-de-Boer Process, CVD (Thermodynamics of CVD Examples), Spray Pyrolysis
- Solvothermal Syntheses
- Silicones and Silazanes: Synthesis from Organo Chloro Silanes,
- Silicon-Containing Polymers: Polysiloxanes, Polysilazanes, Polysilylcarbodiimides, Polysilanes, Polycarbosilanes
- Boron-Containing Polymers
- Polymer-Derived Ceramics and Their Applications (Fibers, Ceramic Brake Disc)
- High Pressure Syntheses, Diamond Anvil Cell
- Sol-Gel Processing I (Alkoxides, Transalkoholyse, Base- und Acid-Induced Catalysis of $Si(OR)_4/H_2O$)
- Sol-Gel Processing II (Polycondensation, Cross-Condensation),
- Organic Light Emitting Diodes
- Biomineralisation

Learning Outcomes, Qualification, and Competence Aims
The student has gained an overview on and remembers different synthesis techniques for inorganic materials. Furthermore, he/she has gained the competence to evaluate the relationship between the synthesis method and the properties of the inorganic materials materials. The student has the competence to evaluate experimental and theoretical methods for goal-oriented research in the area of inorganic materials. The student has a first insight in modern preparative techniques for inorganic materials and a beginner's competence to follow advanced textbooks and scientific literature.

Annotations / Usability of Module*
M.Sc. Materials Science: Elective Course

Prerequisites	**Literature***
none	1. U. Schubert, N. Hüsing: „Synthesis of Inorganic Materials“, Wiley-VCH, Weinheim, 2000 2. David Segal: „Chemical Synthesis of Advanced Ceramic Materials“, Cambridge University Press, 1991 3. Bill, Wakai, Aldinger, „Precursor-Derived Ceramics“, Wiley-VCH, 1996

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Nanomaterials: Synthesis, Size-Dependent Properties and Applications

responsible: **PD Dr. A. Gurlo**

Course	**Module**	**Instructor(s)**
[M.NM] Nanomaterials: Synthesis, Size-Dependent Properties and Applications	Materials Science Advanced Elective Courses	A. Gurlo
Form of Teaching / Credit Hours	**Credit Points**	**Language**
L/2	3	English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every WS	3rd Semester	see University Catalog

Examination Requirements
Graded Examination
Content of Teaching and Examination
• Introduction to nanotechnology. Definitions of nano- . Nanomaterials. Application fields of nanomaterials. Morphology: 0D, 1D, 2D and 3D structures. Clusters and magic numbers. Geometrical and electronic considerations. • Scalable and quantum effects. Influence on band structure, optical, electrical, mechanical, magnetic properties and chemical reactivity. • Electronic structure. Pressure effect. Metals: cluster size effects; metal-to-insulator transition. Kubo criterion (Kubo gap). Semiconductors: quantum dots, electronic confinement, nanophotonics, photochemical and photophysical properties. Bohr exciton radius. Dimensionality effects in quantum structures. Debye screening length. Phase stability and phase transitions at the nanoscale. • Nanostructured materials. Nanostructured materials. Porosity. Types of pores. Use of mercury porosimetry and nitrogen adsorption for characterisation of the porosity and surface area. Estimation of particle size from the gas porosity measurements. Nanoporous materials • Synthesis of nanomaterials. Top-down and bottom-up approaches. Control of driving forces for nucleation and growth for nanoparticle synthesis. LaMer model. Homogeneous and heterogeneous nucleation. Diffusion-controlled growth. Ageing. Shape control. • Synthesis of metal nanoparticles. Synthesis of II-VI semiconductor nanoparticles. Synthesis of oxide nanoparticles. Synthesis of III-V nanoparticles. • Kinetically confined synthesis. Sol-gel synthesis and colloidal chemistry. Hot injection and heating-up methods. Arrested nucleation and growth. • Nanoparticles in heterogeneous catalysis. Nanoparticles for chemical sensing. Recognition. Transduction. Nano-microintegration. Nanosensors. Biological imaging. • Selected (hot) topics from current research
Learning Outcomes, Qualification, and Competence Aims
The student is able explain the size dependent properties, choose the right synthesis method and conditions and to calculate the surface-to-volume ratio, dispersion; specific surface area; number of atoms; Kubo gap, Debye screening length, Bohr exciton radius in materials.
Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Course

Prerequisites	**Literature***
none	1. E. Roduner. Nanoscopic Materials: Size-Dependent Phenomena. Royal Society of Chemistry: Cambridge. 2006 2. D. Vollath. Nanomaterials. Wiles-VCH, 2008. 3. J.-P. Jolivet, Metal Oxide Chemistry and Synthesis: From Solution to Solid State. Wiley, 2000 4. Semiconductor Nanocrystal Quantum Dots: Synthesis, Assembly, Spectroscopy And Applications, Springer, 2009.

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Ceramic Materials: Syntheses and Properties. Part I

responsible: **Prof. Dr. R. Riedel**

Course	**Module**	**Instructor(s)**
[M.CM1] Ceramic Materials: Syntheses and Properties. Part I	Materials Science Advanced Elective Courses	R. Riedel
Form of Teaching / Credit Hours	**Credit Points**	**Language**
L/2	3	English

Expenditure of Work

Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every SS	2nd Semester	see University Catalog

Examination Requirements

Graded Examination

Content of Teaching and Examination

- Introduction: Definitions; Classes of Ceramic Materials; Applications
- Engineering Ceramics: Preparation, Microstructure, Properties
- Thermodynamics (Phase Diagrams, Interface Energies); Kinetics
- Synthesis Techniques of Ceramic Powders
- Carbides: Silicon Carbide (SiC), Boron Carbide (B_4C), Titanium Carbide (TiC)
- Nitrides: Silicon Nitride (Si_3N_4), Aluminum Nitride (AlN), Boron Nitride (BN), Titanium Nitride (TiN)
- Borides, Silicides
- Oxides: Aluminum Oxide (Al_2O_3), Zirkonium Dioxide, Multicomponent Oxides

Learning Outcomes, Qualification, and Competence Aims

The student has gained an overview on and remembers different synthesis techniques for ceramic materials. Furthermore, he/she has gained the competence to evaluate the (micro)structure-properties relationship for ceramic materials. He/she is able to correlate different classes of ceramic materials with specific properties and applications. The student has the competence to evaluate experimental and theoretical methods for goal-oriented research in the area of ceramics. The student has a first insight in modern preparative techniques for ceramic materials and a beginner's competence to follow advanced textbooks and scientific literature.

Annotations / Usability of Module*

M.Sc. Materials Science: Elective Course

Prerequisites	**Literature***
none	1. Allgemeine Lehrbücher für anorganische Chemie 2. U. Schubert, N. Hüsing, „Synthesis of Inorganic Materials“, Wiley-VCH, Weinheim, 2000 3. W. Büchner, R. Schliebs, G. Winter, K. H. Büchel, „Industrielle Anorganische Chemie“, Wiley-VCH, Weinheim, 1986 4. M. W. Barsoum, „Fundamentals of Ceramics“, Institute of Physics Publishing, Bristol and Philadelphia, 2003 5. Salmang, Scholze, „Keramik“ Teil 1 und 2, Springer Verlag, Berlin 1982; ISBN 3-540-10987-0 6. W. D. Kingery, H. K. Bowen, D. R. Uhlmann, “Introduction to Ceramics”, John Wiley and Sons, New York 1976; ISBN 0-471-47860-1 7. W. Schatt, „Einführung in die Werkstoffwissenschaft“, VEB Deutscher Verlag, Leipzig 1972; ISBN 3-342-00190-9 8. H. Scholze, Glas, Natur, „Struktur und Eigenschaften“, Springer Verlag, Berlin 1988, ISBN 3-540-18977-7 9. D. Segal, “Chemical Synthesis of Advanced Ceramic Materials”, Series “Chemistry of Solid State Materials“ 1, Cambridge University Press, Cambridge 1989; ISBN 0-521-42418-6

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*

100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Ceramic Materials: Syntheses and Properties. Part II

responsible: **Prof. Dr. R. Riedel**

Course	**Module**	**Instructor(s)**
[M.CM2] Ceramic Materials: Syntheses and Properties. Part II	Materials Science Advanced Elective Courses	E. Ionescu, R. Riedel
Form of Teaching / Credit Hours	**Credit Points**	**Language**
L/2	3	English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every WS	1st or 3rd Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Disperse Systems
- Powder Processing
- Ceramic Suspensions, Ceramic Slurries
- Fundamentals of Rheology
- Shaping Techniques
- Drying
- Sintering Processes
- *Special Issues (Examples)*: Perovskite Oxides; Thermal Barrier Coatings (TBCs), Environmental Barrier Coatings (EBCs), Ultra High Temperature Ceramics (UHTCs), Polymer-Derived Ceramics (PDCs)

Learning Outcomes, Qualification, and Competence Aims
The student has gained an overview on and remembers different processing techniques for ceramic parts. Furthermore, he/she has gained the competence to evaluate the (micro)structure-properties relationship for ceramic materials. He/she is able to correlate different classes of ceramic materials with specific properties and applications. The student has the competence to evaluate experimental and theoretical methods for goal-oriented research in the area of ceramic materials. The student has a first insight in modern processing techniques for ceramic materials and a beginner's competence to follow advanced textbooks and scientific literature.

Annotations / Usability of Module*
M.Sc. Materials Science: Elective Course

Prerequisites
none

Literature*

1. W. D. Kingery, *Introduction to Ceramics*, Wiley 1976
2. J. R. Reed, *Introduction to the Principles of Ceramic Processing*, Wiley 1987
3. *Materials Sience and Technology*, Vol 17A and 17B, VCH Weinheim, 1996
4. Salmang, Scholze *Keramik 1 +2*, Springer Berlin, 1982
5. U. Schubert, N. Hüsing, *Synthesis of Inorganic Materials*, Wiley-VCH, Weinheim, 2000
6. G. Brezesinski, H.-J. Mögel, *Grenzflächen und Kolloide*, Spektrum, Heidelberg, Berlin, 1993
7. H.-D. Dörfler, *Grenzflächen- und Kolloidchemie*, VCH Weinheim, 1994

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Introduction to Luminescent Materials
responsible: **Prof. Dr. H. von Seggern**

Course	**Module**	**Instructor(s)**
[M.LM] Introduction to Luminescent Materials	Materials Science Advanced Elective Courses	H. von Seggern, J. Zimmermann
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every SS	2nd Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination
- Introduction to spectroscopy
- Electron structure of single electron atoms, multiple electron atoms molecules
- Introduction into group theory
- Bandstructure of solid state bodies
- Selection rules for optical transition
- Isolated centers in a matrix
- Franck-Condon-model
- Energy migration
- Luminescent materials

Learning Outcomes, Qualification, and Competence Aims
The student has a general survey of the physical mechanisms of electronic transitions and a tool to calculate simple optical transitions in atoms, molecules and solids. He/she is able to find symmetries in molecules and can handle character tables and term symbols. The student can distinguish between different mechanisms of energy migration and is able to explain luminescence gain and quenching and their general dependence on activator concentration, matrix, impurities, etc. He/she is introduced to use UV-VIS-spectroscopy methods for the investigation of luminescent materials. The student is prepared to apply fundamental phosphor science to novel materials and has a first insight into modern research in phosphors and a beginner’s competence to follow advanced textbooks and scientific literature.

Annotations / Usability of Module*
M.Sc. Materials Science: Elective Course

Prerequisites	**Literature***
Quantum mechanics for material scientists recommended, basic knowledge in solid state physics	1. G.Blasse, B.C. Grabmaier: Luminescent Materials, Springer Verlag 1994 2. 2.The Phosphor Handbookby Shigeo Shionoya(Editor), Shigeo Shinoya(Editor), William M. Yen (Editor), Publisher: CRC Press; (September 10, 1998) 3. B. Henderson and G. F. Imbusch: Optical spectroscopy of inorganic solids-Oxford : Clarendon Press, 1989. 4. M.D.Lumb: Luminescence Spectroscopy, Academic Press 1978 5. P.W. Atkins, Physikalische Chemie, 2. Auflage, VCH 6. P.W. Atkins, R.S. Friedmann: Molecular Quantum Mechanics, Oxford 1997, 3. Auflage, T. Mayer-Kuckuk, Atomphysik, Teubner Studienbücher 7. Th. Jüstel, H. Nikol, C Ronda: Neue Entwicklungen auf dem Gebiet lumineszierender Materialien für Beleuchtungs- und Displayanwendungen, Angew. Chem. 110, 1998, 3250-3271 (Aufsatz)

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Organic Semiconductors and Devices

responsible: **Prof. Dr. H. von Seggern**

Course	**Module**	**Instructor(s)**
[M.OSD] Organic Semiconductors and Devices	Materials Science Advanced Elective Courses	H. von Seggern, C. Melzer
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every WS	1st or 3rd Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- Electronic structure of organic semiconductors
- Contact formation and charge-carrier injection in organic semiconductors
- Charge-carrier transport in organic semiconductors
- Optoelectronic processes in organic semiconductors
- Preparation of organic semiconductor based devices
- Function of organic semiconductor based devices
- Methods of material and device characterization
- Methods of material and device development

Learning Outcomes, Qualification, and Competence Aims
On bases of the imparted fundamentals about organic semiconductors and devices the student is enabled to judge about the general technological capacity and applicability of organic semiconductors. The broad overview on organic functional materials enables the student to categorize organic semiconductors for specific application. He/she is able to identify the essential material properties and functions relevant for conventional applications and he/she is capable to choose appropriate measures for a material engineering. The student remembers the usual material and device preparation methods and can thus bring material functionality and processability together. He/she is able to choose the appropriate methods to characterize the organic material and the related devices. The student has a first insight in modern research in the field of organic electronics and a beginner's competence to follow advanced textbooks and scientific literature.

Annotations / Usability of Module*
M.Sc. Materials Science: Elective Course

Prerequisites
Solid state Properties I and II and Physical Chemistry I recommended

Literature*

1. C. Melzer and R. Schmechel, “Organische Halbleiter”, lecture material (latest version 2010)
2. M. Schwoerer and H. C. Wolf, “Organic Molecular Solids”, Wiley-VCH (2006)
3. K. C. Kao and W. Hwang, “Electronic transport in solids with particular reference to organic semiconductors”, Pergamon Press, Oxford (1981)
4. M. Pope and C. E. Swenberg, “Electronic processes in organic crystals”, Univ. Press, Oxford (1982)

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Scanning Probe Microscopy in Material Science

responsible: **Prof. Dr. R. Stark**

Course	**Module**	**Instructor(s)**
[M.SPMMS] Scanning Probe Microscopy in Material Science	Materials Science Advanced Elective Courses	R. Stark, C. Dietz
Form of Teaching / Credit Hours	**Credit Points**	**Language**
L/2	3	English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every SS	2nd Semester	see University Catalog

Examination Requirements
Graded Examination
Content of Teaching and Examination
• Introduction into nanoscience and nanotechnology • Scanning force microscopy • Scanning tunneling microscopy • Scanning nearfield microscopy
Learning Outcomes, Qualification, and Competence Aims
The student is familiar with the basic concepts of nano- and microfabrication techniques. He/she has gained insights into contact mechanics and surface forces and is able to apply the appropriate model to a nanomechanical experiment. The students have achieved an extensive overview on established surface characterization techniques based on scanning probe microscopy including the physical principle, instrumentation, modes of operation and can explain underlying physical principles. The students can explain the interplay between manufacturing and evaluation/characterization in nanoscience. The students can analyze and explain physical phenomena at solid liquid interfaces. The students know how to select the adequate methods and to apply an appropriate but yet simple model to study nanophysical properties of soft and hard matter.
Annotations / Usability of Module*
M.Sc. Materials Science: Elective Course

Prerequisites	**Literature***
none	1. B. Bhushan (Ed.), *Handbook of Nanotechnology*, Springer, Berlin Heidelberg, 2010. 2. E. Meyer, H. J. Hug, R. Bennewitz, *Scanning Probe Microscopy*, Springer, Berlin Heidelberg, 2004. 3. R. Garcia, *Amplitude Modulation Atomic Force Microscopy,* WILEY-VCH, Weinheim, 2010. 4. J. Israelachvili, *Intermolecular & Surface Forces*, Academic Press, London, 1992. 5. H.-J. Butt, M. Kappl, *Surface and Interfacial Forces*, WILEY-VCH, Weinheim, 2010.

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

Materials research with energetic ion beams - basic aspects and nanotechnology

responsible: **Prof. Dr. C. Trautmann**

Course	**Module**	**Instructor(s)**
[M.MREIB] Materials research with energetic ion beams - basic aspects and nanotechnology	Materials Science Advanced Elective Courses	C. Trautmann
Form of Teaching / Credit Hours L/2	**Credit Points** 3	**Language** English

Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h

Module Offered	**Recommended Semester***	**Weekday/Time/Place***
Every SS	2nd or 4th Semester	see University Catalog

Examination Requirements
Graded Examination

Content of Teaching and Examination

- **ionizing radiation**
- **particle-solid interaction**
- **energy loss**
- **accelerator technology**
- **radiation damage**
- **damage analysis**
- **nanotechnology with ion beams**

Learning Outcomes, Qualification, and Competence Aims
The course provides an overview of the unique possibilities using high-energy heavy ions for the modification of material properties and production of micro and nanostructures. The student becomes familiar with basic interaction processes of particle beams and solids. Knowledge is gained how ion radiation deteriorates materials and how this radiation damage is analysed by different methods. The lecture also gives insight in ion beam technology at large scale accelerator facilities and how to perform irradiation experiments by adjusting and controlling specific beam parameters. The course will also provide a glimpse on the present activities in the field of ion track technology using individual ion projectiles as structuring tool. The students will be familiar with ion-beam produced micro- and nanostructures and a broad spectrum of applications. At the end of the course, the students have the chance to visit the large accelerator facility of GSI including different beamlines devoted to materials research.

Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Course

Prerequisites	**Literature***
none	Will be provided during the lectures

Form of Examination*	**Length of Examination***
oral	30 min

Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.

* optional information

Micromechanics and Homogenization Techniques
responsible: **J.-Prof. Dr. B.-X. Xu**

<table>
<tr><td colspan="2">Course
[M.MHT] Micromechanics and Homogenization Techniques</td><td colspan="2">Module
Materials Science Advanced Elective Courses</td><td>Instructor(s)
B.-X. Xu</td></tr>
<tr><td colspan="2">Form of Teaching / Credit Hours
L/2 and E/1</td><td colspan="2">Credit Points
4</td><td>Language
English</td></tr>
<tr><td colspan="5">Expenditure of Work
Lecture: 30 h, Homework: 30 h, Preparation for Examination: 30 h: Sum: 90 h</td></tr>
<tr><td>Module Offered
Every SS</td><td colspan="2">Recommended Semester*
3rd Semester</td><td colspan="2">Weekday/Time/Place*
see University Catalog</td></tr>
<tr><td colspan="5">Examination Requirements
Graded Examination</td></tr>
<tr><td colspan="5">Content of Teaching and Examination
Materials show a multitude of heterogeneities due to microstructure, defects or grain boundaries in a generalized sense. In micromechanics one investigates the influences of these heterogeneities or defects at microscale on the overall mechanical properties and performance of a material at macroscale. This micro-to-macro transition formally proceeds by appropriate averaging processes and is called homogenization. This lecture starts with a brief introduction to continuum mechanics and then focus on the fundamental analytical and computational homogenization techniques.
• Introduction to Continuum Mechanics
• Basic Tensor Analysis
• Concept of Representative Volume Element
• Effective elastic properties
• Energy methods and bounds
• Introduction to Computational Homogenization</td></tr>
<tr><td colspan="5">Learning Outcomes, Qualification, and Competence Aims
After this lecture one can handle basic tensor operation and stress and strain analysis in a material. More important, the students attain basic conception and techniques of homogenization. Using these techniques, he/she can calculate the effective properties, e.g. Young’s modulus or piezoelectric constants, of an inhomogeneous composite material. He/she will have the competence to follow advanced textbooks and scientific literature on composite mechanics in materials science.</td></tr>
<tr><td colspan="5">Annotations / Usability of Module*
M.Sc. Materials Science Advanced Elective Courses</td></tr>
<tr><td>Prerequisites
Technische Mechanik II</td><td colspan="4">Literature*
1. D. Gross, Th. Seelig, Fracture Mechanics – with an introduction to Micromechanics, Springer, Berlin, 2rd edition, 2011
2. J. Aboudi, Mechanics of Composite Mechanics – A unified Micromechanical Approach. Amsterdam, 1991
3. K.C. Le, Introduction to Micromechanics. Nova Science Publ. Inc. 2010
4. T. Mura, Micromechanics of Defects in Solids. Martinus Nijhoff Publisher, Dordrecht, 1987
5. T.I. Zohdi, P. Wriggers, An Introduction to Computational Mechanics, Springer, Berlin, 2008</td></tr>
<tr><td colspan="3">Form of Examination*
oral</td><td colspan="2">Length of Examination*
30 min</td></tr>
<tr><td colspan="5">Grade Composition*
100% oral examination. The oral examination comprises two or more matched Materials Science Advanced Elective Courses.</td></tr>
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* optional information