Master of Science
"Crystalline Materials"
Course Descriptions

CRYS 41: Crystal Growth I

CRYS 411: Crystal Growth Technology
A short overview of crystal growth methods, followed by a discussion of current aspects of bulk crystal growth: use of external fields, high pressure growth, thermodynamic equilibria in growth systems, problems of large industrial crystals, simulation tools.

CRYS 412: Crystal Growth Methods I
Laboratory crystal growth experiments in float-zone growth, solution growth, gel growth, and vapor phase growth.

CRYS 42: Advanced Crystallography

CRYS 421: Crystallographic Methodology
The course starts with a short introduction of the concepts of symmetry and crystallographic notation, followed by applied aspects of group theory, black and white groups, and color groups and their applications. The concept and examples of quasicrystals will be presented.

CRYS 422: Space Groups and Crystal Structures
The symmetry of any atomic arrangement in a crystal can be described by one of the 230 different crystallographic space groups. A first part of the course deals with principles of space group structure, notation and visualization. The most important basic crystallographic atomic arrangements are treated in a second part, starting from closest sphere packing structures.

GEOL 42: Computer Methods

GEOL 421: Computer Methods
Geological systems are complex ones, therefore data on them can seldom be analyzed effectively without the help of appropriate computer-based methods. By the same token, computer-based models are necessary to provide insight into their parent systems. The course covers the theory of the commonly used analytical and modeling methods; these are illustrated

using numerous case studies. The importance of interactive visualization techniques is stressed.

GEOL 43: Analytical Methods

GEOL 431: Physical Analytical Procedures
GEOL 432: Chemical Analytical Procedures
These two courses are designed to introduce the theory, applications, and operation of modern instrumental methods for chemical analysis in environmental, Earth and materials science. Students will be introduced to the spectrum of instrumental techniques which are standard in research as well as in industry and will gain an understanding of the analytical approach to problem solving. To the extent feasible, students will get hands-on experience with the machinery in the course of lab exercises, concentrating on concrete small analytical projects.

CRYS 51: Advanced Analytical Methods

CRYS 511: High-Resolution Spectroscopy
The course provides tools for the characterization of crystalline materials, especially the type and site of atoms as well as their first sphere surroundings. The methods of surface analysis using X-ray Photon Spectroscopy (XPS), Secondary Ion Mass Spectroscopy (SIMS) and Auger Spectroscopy (AGS) are introduced and compared to their characteristics and limitation of material analysis. To analyze the local geometry, the chemical state and coordination spheres of atoms X-ray Absorption Spectroscopy (XAS), Extended Absorption Fine Structure (EXAFS), and X-ray Absorption Near Edge Structure (XANES) will be presented; this part includes an introduction into synchrotron technology. To find the oxidation state of atoms (e.g., Fe^{2+}, Fe^{3+}) the Mössbauer Spectroscopy will be explained.

CRYS 512: X-Ray Diffraction by Crystals
Methods which make use of the diffraction of X-rays (or neutrons) by crystals yield much more detailed and precise knowledge on the arrangement of atoms in matter than any other methods. This course teaches the principles of X-ray diffraction starting from two point scatterers and ending at an (ideally infinite) crystal structure and its "structure factors". The geometric relationships between crystallographic lattice planes on one side, incident and diffracted beams on the other, are explained by means of the reciprocal lattice and the Ewald construction. Requires CRYS 422.

CRYS 52: Crystal Growth II

CRYS 521: Growth Kinetics
The macroscopically stable faces of a crystal are a function of the lattice structure. The incorporation of species into lattice positions depends on the real surface structure of the interface as well as on the growth mode. Anisotropies result in a non-uniform composition on a micro scale. The microscopic growth mechanisms which produce such inhomogeneities and morphological instability are the topic of this course. The microsegregation of impurities will be explained in terms of molecular kinetic models.

CRYS 522: Crystal Growth Methods II
Laboratory crystal growth experiments in Bridgman growth and high temperature solution growth will be performed and the resulting crystals will be compared.

CRYS 523: Crystal Preparation
The course contains laboratory experiments on orientation, cutting, and etching of crystals; an introduction into Nomarski differential interference contrast microscopy will be given.

CRYS 524: Epitaxy
Growth of epitaxial layers and deposition of thin films are playing an important role in development and applications of devices and tools. This course will give an overview of different epitaxial growth methods and deposition technologies from solution and vapor phase. The Chemical Vapor Deposition CVD, the Physical Vapor Transport PVT, Metal Organic MOCVD, and Molecular Beam Epitaxy MBE will be presented.

CRYS 53: Applied Materials I

CRYS 531: Crystal Physics
The course introduces technologically important physical properties of crystals based on their anisotropy, such as nonlinear optics, piezoelectricity, ferroelectricity, ferroelasticity. The basic tools for describing these properties (tensors) as well as some technical applications of these crystals will be discussed.

CRYS 532: Semiconductors
The course introduces the physics of semiconductors regarding the electronic structure and the consequences for the material properties. The effect of impurities, dopants and defects are taught for the semiconductors silicon, GaAs, GaN, ZnO and ternary compounds. The electrical, structural and optical characteristics are compared to the performance of semiconductor devices.

CRYS 54: Defects

CRYS 541: Crystal Defects
Crystals never have an ideal structure, and crystal defects influence physical properties and applications considerably. The course will introduce types (0-D to 3D), causes, and effects of crystal defects, such as color centers, dislocations, stacking faults, twinning.

CRYS 542: Electrical and Optical Characterization Methods
This course gives an overview of the optical and electrical characterization methods for crystalline materials. The resistivity of semiconductors and insulators can be determined by the Van-der-Pauw method and Four-Point-Probing. The mobility can be measured using a Hall geometry. The spectral response of excitation by light is recorded with a spectrometer for different light sources.

CRYS 61: Applied Materials II

CRYS 611: Semiconductor Technology
The topic of this course is the planar technology for fabrication of semiconductor devices. The methods of planar technology are described starting from photolithography and continuing with etching technologies, doping by diffusion and ion implantation. The principles of CMOS and Bipolar Transitors devices are presented using the device processing of the planar technology. A detailed overview of state of the art of semiconductor devices like CCD, LED and DRAM concludes the course.

CRYS 612: Electric Characterization of Crystals and Devices
Laboratory experiments on the measurement of resistivity, piezoelectric, pyroelectric, and ferroelectric constants in crystals will be carried out. The principles of photolithography and structured contacts are carried out for a simple device structure. The performance of this structure is measured by I-V characteristics. Conventional semiconductor devices will be tested by I-V, C-V and optical methods.

CRYS 62: Analytical X-Ray Methods

CRYS 621: Structure Analysis by X-Ray Diffraction
In a first part, methods to determine lattice parameters and space group of a single crystal and to measure the intensities of diffracted beams are discussed. Then, the course deals with different ways to solve the crystal structure (i.e., to determine the atomic arrangement and more). In a final part, methods to solve and refine crystal structures from powder diffraction patterns are treated. Requires CRYS 512.

CRYS 622: Defect Analysis by Diffraction
Position and intensity of a Bragg reflection are used for structure analysis of a crystal. In addition, the fine structure of such a reflection contains information about the real structure of this crystal. In terms of dynamical diffraction theory defects are characterized using high-resolution diffractometry. Rocking curves and reciprocal space maps are demonstrated to give insight into the crystal quality. X-ray topography will be discussed as a useful imaging method for strain fields around extended defects.

CRYS 63: Technical and Applied Mineralogy

CRYS 631: Modern Ceramics, Cements, and Glasses
Polycrystalline and amorphous materials play a major role in modern technology. The course will cover the production methods of technical ceramics, cements, and glasses, as well as their applications.

CRYS 632: Thermal Analysis
After a short introduction of the underlying thermodynamics the course deals with the principles of Differential Thermal Analysis (DTA), Differential Scanning Calorimetry (DSC), and Thermal Gravimetry (TG). A phase diagram is constructed based on DTA measurements. The exact chemical composition of a substance is determined by TG/DSC measurements.

CRYS 64: Field Trips and Seminars

CRYS 641: Seminar: Recent Publications
Seminar on current trends in crystal growth, characterization, and applications of crystalline materials.

CRYS 642: Advanced Seminar on In-House Research
Seminar on current research projects in the institute

CRYS 643: Field Trips to Industrial Facilities
Field trips to companies and research institutes involved in the production and use of technologically important crystal materials

Special Topics in Crystalline Materials and Geoscience (Elective Courses)

CRYS 525: Purification and Doping Methods
The course teaches vacuum and clean room technologies, followed by the major methods for purification of materials (rectification, sublimation, crystallization). An overview of doping methods for bulk crystals will be given.

CRYS 533: Semiconductor Devices
The course covers the wide field of semiconductor devices, including diodes, transistors, optical detectors, memory devices and X-ray detectors.

CRYS 551: Electron Back Scatter Diffraction
In this advanced course of scanning electron microscopy (SEM) the diffracted electrons are used to analyze the orientation of crystals. The basics of electron back scatter diffraction (EBSD) will be presented in theory and practice. Main parts of the course are practical exercises at the SEM to measure and interpret textures in natural rocks or polycrystalline materials (e.g. solar cells). Requires modules CRYS 42 and GEOL 43.

CRYS 644: Special Topics in Materials Science
This course will present topics that vary each year. It is designed for advanced M.Sc. students. Specific topics will be discussed with the students and then selected according to prevailing interests.

GEOL 433: Special Analytical Procedures in Mineralogy
The emphasis of this course is on important mineralogical techniques used in ore geology, petrology, soil science and environmental science. The students explore the various methods both in theory and in the laboratory, where hands-on experience is an essential part of the course.

GEOL 441: Aqueous Geochemistry
Waters from the ocean, lakes, rivers, groundwater and deep-water reservoirs in the crust participate fundamentally in geological processes. The waters acquire a specific chemical composition by chemical reaction with minerals and rocks and by interaction with the atmosphere and the biosphere. The quantitative treatment of chemical processes in natural waters is the topic of this course. The students will be enabled to interpret and understand the chemical evolution of natural waters.

GEOL 442: Chemical Modeling of Natural Waters
The chemical composition of natural waters contains a wealth of information on the origin of the waters, their flow paths and their potential further evolution. In this course students learn to analyze chemical water composition data with the help of modern software tools with the aim to understand the chemical processes that determine the composition of natural waters.

GEOL 551: Energy, Waste, and the Environment
This course covers a wide range of problems associated with the waste arising from the generation of electricity. The main topics will be the uranium cycle; characterization of nuclear waste; containment and disposal of nuclear waste; characterization of coal combustion products; disposal and reuse of coal combustion products; CO_2 sequestration; incineration of municipal solid waste and incineration products; landfills and landfill gases; waste as resource.

GEOL 612: Geomechanical Modeling
The course introduces the various material laws, which can be used to describe the mechanical behavior and deformation of rocks. Numerical methods, in particular finite element techniques, will be used to predict tectonic stresses and fractures in geothermal and hydrocarbon reservoirs.

Geoscience Courses from B.Sc. Curriculum
Students with a B.Sc. degree in a Non-Geoscience field will have to select a number of courses from the B.Sc. program at the University of Freiburg. Students with a B.Sc. degree in Geoscience from another university may also have to take some courses from our B.Sc. program to make up for deficiencies.