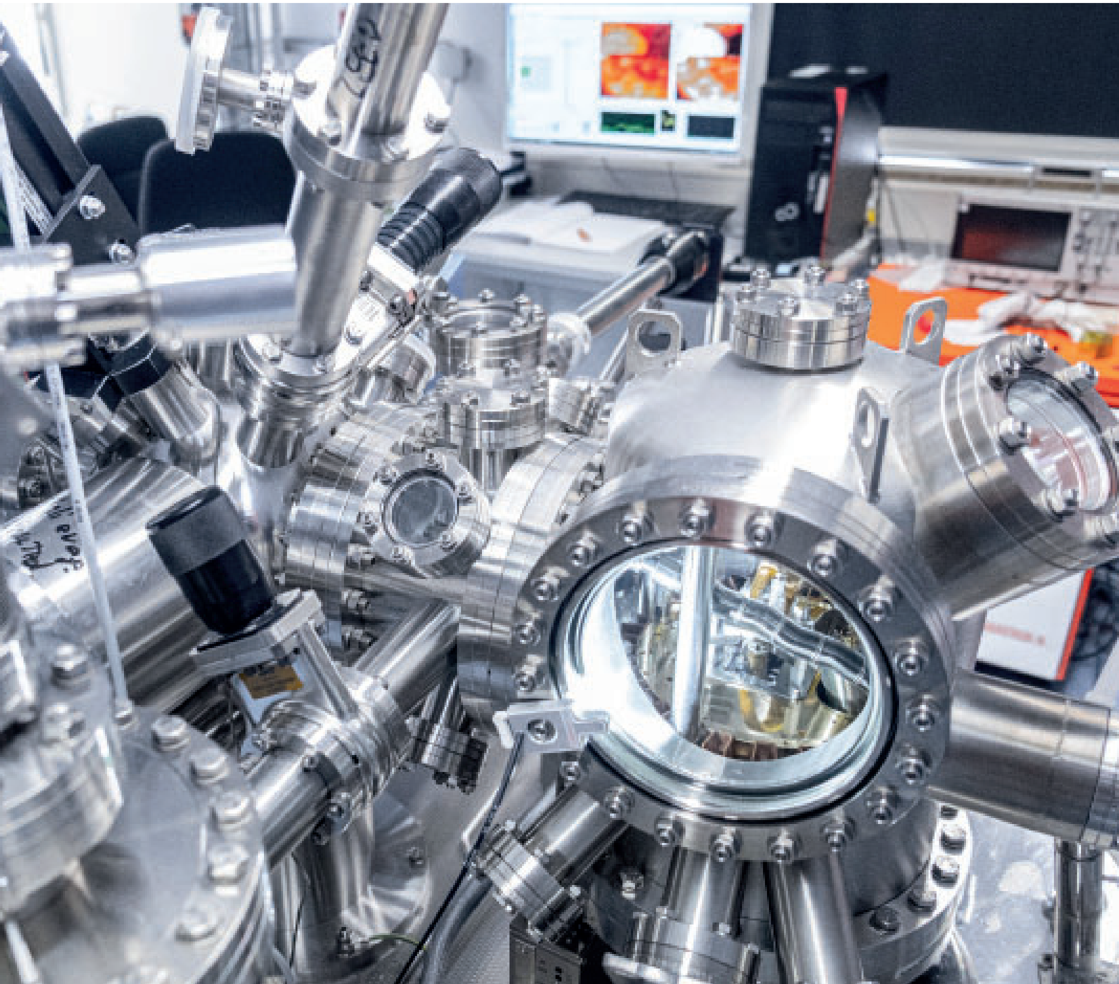
Universität Siegen

Master of Science (Physics)

Focus Area: Solid State Physics

Description of the Study Program



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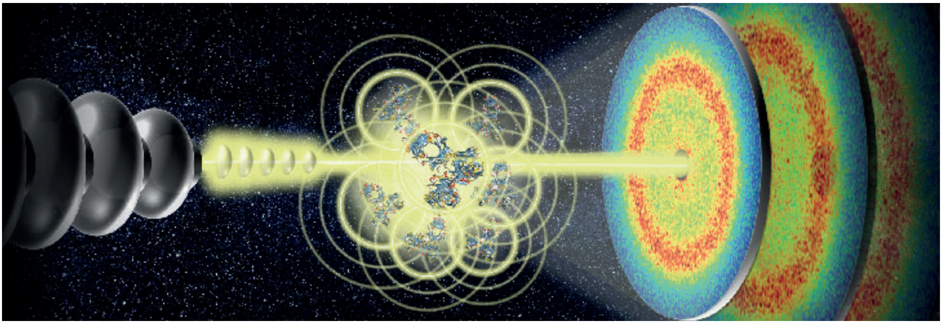
Instagram-Channel Faculty IV

Introduction

Take a look around and you will see **solid state physics at work:** you can read on a computer screen because of a clever interplay between semiconductor electronics and the molecular properties of liquid crystals. Electrical currents can be transported in wires through our power grids because their atoms have metallic bonds in which the electrons can move almost freely. Your smartphone works because electrons are directed at will with high speed in nanoscale networks. When you write with a pencil you cleave the graphite crystals in its core and leave behind thin flakes of carbon on the paper. Your body is an amazing assembly of hard and soft condensed matter with biomolecules in water performing their work relentlessly, everything held together by the molecular networks of soft tissues and hard bones. In the **two-year international study program Master of Science (Physics)** with focus on **Solid State Physics** you will learn the underlying fascinating physical effects which are ruling this nano-cosmos.



"More is different" is a famous quote in solid state physics: when many atoms get together to form solids and molecules, suddenly a hierarchy of length and time scales can appear driven by the basic laws of physics. This is when things get really interesting! Having more than a few atoms enables biomolecules to form and fold, water to display its unusual properties, atomic sheets in materials to emerge with superconductivity, magnetic skyrmions to arise out of magnetic disorder and graphene to acquire its unique electronic and mechanical properties - to name just a few examples.

Solid state physics is the most active field of contemporary physics producing some of the **biggest scientific and technological breakthroughs in modern times.** It is a very broad field and encompasses diverse topics such as semiconductor physics, magnetism, nanostructures, crystallography, low temperature physics and soft matter physics. It is characteristic for solid state physics that **fundamentals and applications** often lie side by side. Prominent examples are microelectronic devices such as computers and smartphones, which were developed from basic research activities in semiconductor physics. Solid state physics is complex, exciting, and full of new and profound ideas with no less than **50 Nobel Prizes** awarded in this field. The research ranges from the development of new technical applications to highly abstract theories. It includes questions and topics that can only be tackled by applying modern data science tools. Solid state physics provides an understanding of the world around us, from the structure of matter to the physical principles of electronic devices. Often, solid state systems serve as nanoscale laboratories to investigate fundamental problems in quantum or statistical physics.

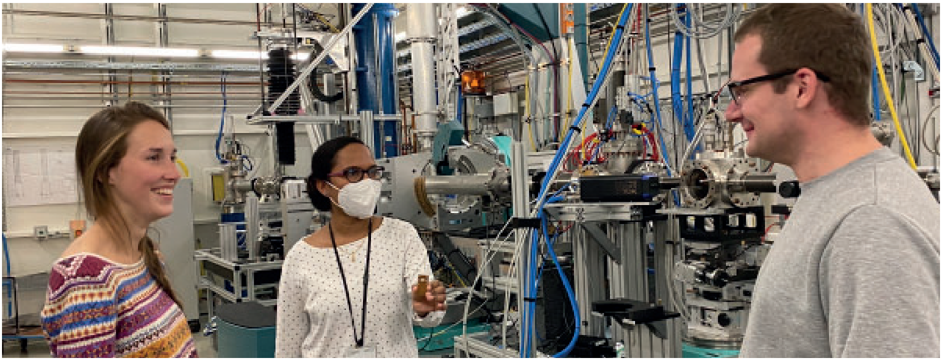
An education in solid state physics not only lays the seeds for true innovations in the future, it also provides our students with well-trained skills of clear analytical thinking, data science tools, hands-on experimental experiences and clever application of scientific methods. Due to this **broad portfolio of skills,** solid state physicists have a **very wide employability,** ranging from fundamental science over research and development in various disciplines and industries, to banking, consulting and insurance and further to management and politics.

The Department of Physics has played a vital part in the research and education profile of the University of Siegen since its foundation in 1972. Research and education in solid state physics in Siegen is embedded into the international context of excellent local research laboratories and world leading large scale synchrotron and X-ray free-electron laser facilities. Students can specialize in ***Solid State Physics*** *within the study program* ***Master of Science (Physics)****. We offer tailored courses designed to introduce students to the theoretical concepts and experimental methods of this field.*

Program Objectives

The study program **Master of Science (Physics)** with focus on **Solid State Physics** qualifies students to tackle research questions at the forefront of science in solid state physics. The program is designed for **four semesters.** The first two semesters are covered by a course program of lectures, seminars, and a laboratory course. The third semester is dedicated to preparing for the actual research work in the laboratories while the Master thesis is prepared and written in the fourth semester.

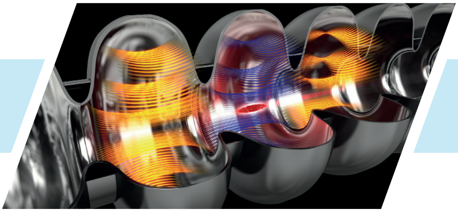
Aside from the scientific specialization, which qualifies students for an academic or research career, the program aims at providing **additional skills and competences**. Being embedded in an international research environment, the students acquire intercultural as well as teamwork competencies. The students learn to develop management plans for handling experimental research and research data. Further skills, such as analytical thinking, scientific writing, pragmatic problem solving, presentation and IT skills including efficient use of digital media are amongst the qualification goals, ensuring an outstanding employability of our graduates.



After completion of the master program, students with outstanding records are encouraged to join a **doctoral program**. The Department of Physics at the University of Siegen offers a broad range of opportunities to pursue research in solid state physics at the doctoral level, and the main research directions of the research groups are listed at the end of this booklet. The doctoral program builds on the specialised courses offered in the master program, which facilitates the transition to the doctoral studies and which in turn embeds the master students in a lively and intensive research program, in which they learn early on what research in solid state physics consists of.

Admission requirements

To enter the study program **Master of Science (Physics)** with focus on **Solid State Physics** a qualified Physics Bachelor is required (exceptions are possible). Solid foundation of the mathematical methods as well as a good knowledge of introductory physics courses is needed.



Structure of the program

The **Master of Science (Physics)** with focus on **Solid State Physics** has a modular structure and it comprises a **one-year phase of course work** followed by a **one-year research phase**. The workload for individual modules is specified using credit points (CP) according to the European credit transfer and accumulation system (ECTS). For the complete master program, the workload amounts to 120 CP, with 1 CP translating into 30 work hours.

Course work phase

The course work phase comprises different types of courses (Mandatory, Core and Elective) and is structured as follows:

Course Type	Components	Credit points
Mandatory courses	Laboratory course	Selection of experiments adding up to 9 CP
	Master Seminar	6 CP
Mandatory Core Modules and chosen Elective	Core module “Experimental Solid State Physics” + one elective from Solid State Physics	15 CP
	Core module 2	9 CP
Electives	Selection of electives or further core modules	21 CP

Laboratory Course

In the Laboratory Course the students will train and advance their experimental skills. The students can choose up to six lab projects from about a dozen on offer. The following selection of projects falls into the focus area Solid State Physics:

- Scanning Tunneling Microscopy
- Atomic Force Microscopy
- X-Ray Reflectivity
- Silicon Photomultiplier
- Surface Plasmon Resonance Based Sensing
- Optically Detected Magnetic Resonance
- Laser Spectroscopy
- Semiconductor Detectors and Electronics

Students may choose further projects from other focus areas offered by the study program **Master of Science (Physics).**

Master Seminar

The Master Seminar is a seminar series covering current research topics in solid state physics. It broadens the student's knowledge about physics research beyond what is covered in the lecture program. The students prepare oral presentations followed by in-depth discussions.

Core Modules and Electives

Students choose their lectures from Core Modules and Electives as shown in the table below. The mandatory core module "Experimental Solid State Physics" is complemented by a 6 CP elective module from the Solid State Physics curriculum. An Oral Exam after passing the individual modules puts the acquired knowledge into a broader context by highlighting the relation between the two modules. Additional knowledge and skills are acquired by attending a second Core Module.

As a general rule the students are required to obtain at least a total of 9 CP from courses from theoretical physics to ensure a solid understanding and overview over the field of physics as needed on the level of a Master of Science. Those 9 CP may be achieved by choosing either a theory Core Module or an appropriate number of Electives from theory.

Core Modules	Electives from Solid State Physics
• **Experimental Solid State Physics (Exp., 9 CP)** • Experimental Quantum Optics (Exp., 9 CP) • Experimental Particle Physics (Exp., 9 CP) • Quantum Information Theory (Theo., 9 CP) • Foundations of Quantum Mechanics (Theo., 9 CP) • Theoretical Particle Physics I (Theo., 9 CP) • Theoretical Particle Physics II (Theo., 9 CP)	• Modern Methods of X-ray Science (6 CP) • Physics of Biological and Soft Matter (6 CP) • Solid State Physics of Nanostructures (6 CP) • Instrumentation at Large Scale Synchrotron Radiation Facilities (3 CP) • Data Analysis and Management in Research with Synchrotron Radiation (6 CP) • X-ray Tomography (6 CP) • Theoretical Solid State Physics (6 CP) • Nano-optics (6 CP) • Nano-biophotonics (6 CP)

We recommend a clear focus on Solid State Physics, however it is also possible to choose Elective Courses from other Focus Areas in Physics or from other departments such as Mathematics (e.g. Data Mining), Chemistry (e. g. Materials for Energy Storage and Conversion, Methods and Techniques of Surface Analysis), Computer Science (e. g. Machine Learning) or Electrical Engineering (e. g. Nanotechnology), or even from other faculties. For modules outside of Physics the students need to contact the Examination Office in advance and check the eligibility.

The content of all courses is described in the Module Handbook and is available on the website of the study program **Master of Science (Physics).**

Research Phase

The research phase consists of three modules, which cover a one-year period fully dedicated to a research project in a specialized area ending with the preparation of the master thesis. During this phase the students **join a research group** of their choice in the department and become active group members. This phase is individually organized according to the needs of the projects.

The research phase starts with a Preparation Phase (15 CP) in which the students familiarize themselves with the scientific questions of the research topic. This comprises studying the relevant literature, understanding the experimental methods used in the research group and the scientific information which can be deduced from the experiments. The following Training Phase (15 CP) consists of a hands-on training approach to the research work including designing experimental setups and strategies, participation in measurement campaigns for example at external facilities and application of data analysis tools. Finally, in the Master Thesis (30 CP), the students shall demonstrate an understanding of the state-of-the-art in the field and **contribute to the scientific progress** in the chosen research topic.

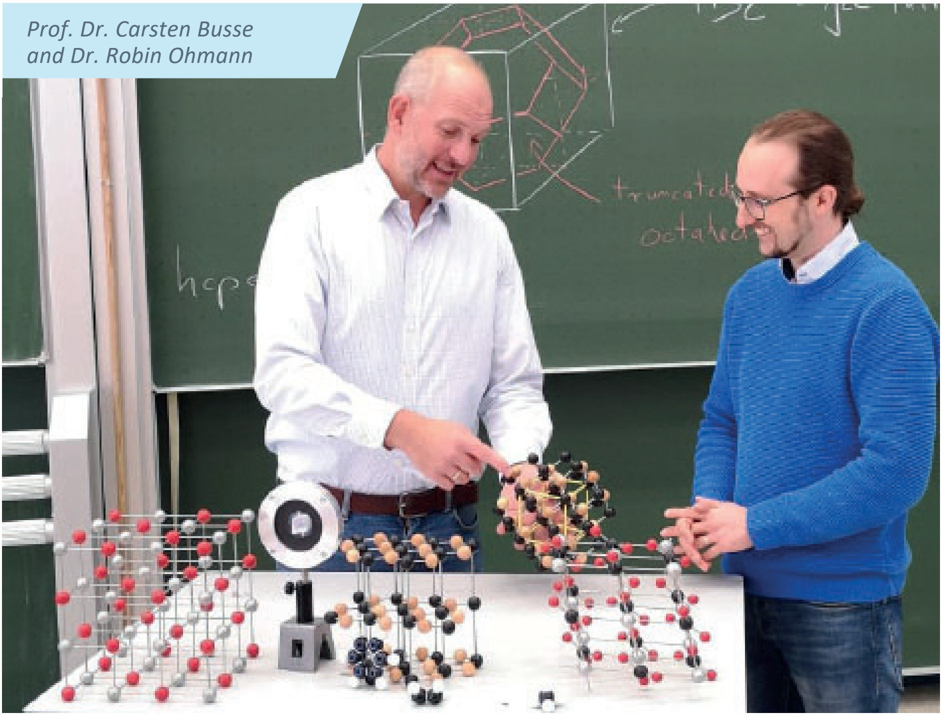
» Physics was my favorite subject already in high school. My first reason to choose the University of Siegen was because I am from the region, but later I found that there are many more positive aspects. If I could go back in time, I would choose Siegen again. The physics campus is cozy, and the sense of community is unique. The teachers know the students by name, which opens the door to incorporation into the research groups early on. In my research project I was responsible for a scanning tunneling microscope, which we used to obtain fascinating images of surfaces of solid state systems with atomic resolution. One of my images even ended up in a physics textbook! «

Joshua Fuhrmann
Master of Science in Siegen, now PhD student in Marburg

Solid State Physics - Prof. Dr. Carsten Busse

We prepare and characterize **ultrathin 2D-Materials** using methods of surface science. Starting with the prototypical graphene (Nobel Prize in Physics 2010), which consists of a single atomic layer of carbon, many new members of this material class have been discovered in recent years. Theoretically hundreds of different materials are possible, however until now only a few have been synthesized.

Our main method for investigation is scanning tunneling microscopy (STM) which allows atomic resolution. We prepare advanced 2D-Materials such as composites of graphene and hexagonal boron nitride or ultrathin semiconductors such as MoS_2 under well controlled conditions, and modify those layers specifically, to for example dope them or investigate the interaction with potentially harmful gases from the environment. In recent years we could show that electrons can be confined in quantum dots made of graphene, how graphene can be destroyed through irradiation with ions, and how impurity atoms are able to sneak in between (intercalate) the 2D-Materials and the supporting substrate.



Prof. Dr. Carsten Busse and Dr. Robin Ohmann

» The master's degree in physics at the University of Siegen in the field of solid state physics was excellent. It's a great working atmosphere there, there are many interesting projects and running experiments in which the student also has their own creative freedom and is always supervised by very nice, competent and helpful professors, postdocs and doctoral students. This degree opened doors to the world of 3D cameras at pmd technologies, where I now work as a laboratory and systems engineer. I would do this again! «

Daniel Weber
Master of Science in Siegen, now at pmd

Questions that you can work on for your Master theses

- There are many theoretical predictions for novel 2D-Materials. Which ones can be experimentally realized?
- Can we understand the properties of a two-dimensional pn-junction using models from the 3D world?
- What happens when we reduce dimensionality even further to 1D (edges and grain boundaries in 2D-Materials)?
- Is it possible to take our scanning tunneling microscope to high schools and let the pupils study surfaces in atomic resolution on their own?
- Can you tune the properties of 2D-Material by ion irradiation?
- How does the physics of 2D-materials change when you expose them to ultra-low temperatures?
- Can 2D-ferroelectrics be used as a non-volatile memory?
- Which novel ultra-thin materials could be used for solar cells?

X-Ray Physics - Prof. Dr. Christian Gutt

We investigate **dynamic processes in hard and soft condensed matter systems** using modern X-ray scattering methods at large scale X-ray research facilities such as DESY, European XFEL, FERMI (Trieste), ESRF (Grenoble), SACLA (Japan) and LCLS (Stanford). The unprecedented brilliance of large scale X-ray facilities enables cutting edge science which has resulted in more than 30 Nobel Prizes in Physics, Chemistry and Medicine.

Our work is highly interdisciplinary and embedded **in a large international research network.** We are especially interested in the dynamics of dense protein systems and we address fundamental questions of diffusion of proteins in crowded environments in the context of biological function and phase separation. We employ and develop the method of X-ray photon correlation spectroscopy (XPCS) to investigate the dynamic processes and diffusion properties on the relevant time and length scales.

View into the 2.1-kilometre long accelerator tunnel of European XFEL with the yellow superconducting accelerator modules hanging from the ceiling.

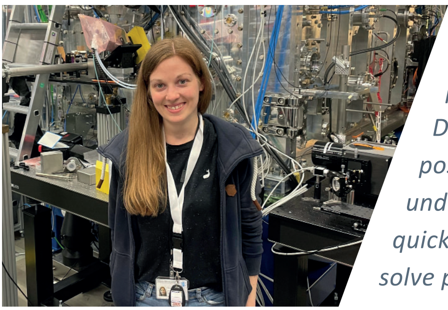
Data from X-ray scattering experiments are becoming increasingly large and multidimensional. The process of converting these data sets to useful scientific information is challenging. Using today's computing powers and software packages we apply popular **machine learning methods** to predict and extract physical properties from big data sets possibly in real time.

» The physics program in Siegen is broad and you learn about physics from the smallest particle to processes in the universe. In the bachelor's and master's theses we are performing research in the experimental groups. During our master thesis we were studying the dynamic processes occurring during phase separation in dense protein solutions, a very active field of research in biophysics. «

Sonja Timmermann and Mohammad Akhundzadeh
Master of Science in Siegen, now PhD students in Siegen

Examples of Master theses

- Dynamics in phase separating proteins classified by auto-encoder networks
- Casein micelles investigated by X-ray photon correlation spectroscopy
- Arrested phase separation in protein solutions
- Pressure induced liquid-liquid phase separation in water-lysozyme solutions
- Dynamics of insulin and tau protein during phase changes measured via XPCS
- Dynamics of Ionic liquids using XPCS with a PN-CCD detector
- Surface dynamics after ultrafast laser-matter interactions studied via GISAXS
- Construction of a dynamic light scattering setup
- Implementing a fast avalanche photo diode for dynamic light scattering
- Ferroelectric domain wall dynamics characterized by coherent X-ray scattering
- Investigating ultrafast surface dynamics of magnetic structures using the FERMI FEL



» What I particularly liked about studying physics in Siegen was the nice atmosphere. During lectures and seminars it was always possible to ask questions directly if you didn't understand something. In addition, you could quickly establish contact with other students and solve problems together. «

Dr. Lisa Randolph
Master of Science in Siegen, PhD in Siegen, now scientist at the European XFEL in Hamburg

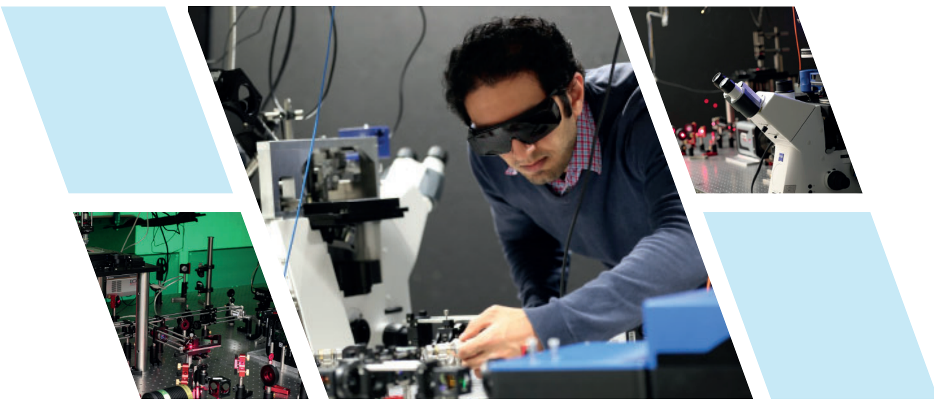
Laboratory of Nano-Optics - Prof. Dr. Mario Agio

The Laboratory of Nano-Optics encompasses experimental and theoretical research activities in Quantum Nano-Optics, Nano Spectroscopy and Nano Sensing, in tight cooperation with local, national, and international research groups. We investigate the properties of light beyond the diffraction limit and study its interaction with nanoscale matter, specifically the interrogation of single quantum systems and the exploration of quantum phenomena that occur at the sub-wavelength scale. Whilst addressing fundamental questions related to light, matter and their interaction, our efforts may also make their way into practical devices, such as a new class of light-sources, sensors, and functional materials. In detail we focus on the following research directions:

Quantum Nano-Optics: We are particularly interested in coupling novel quantum emitters to nanoscale resonators and in investigating such hybrid systems using ultra-fast techniques that may allow us to explore quantum phenomena in the presence of strong decoherence.

Nano Spectroscopy: Using concepts such as nanofocusing, we aim at implementing advanced spectroscopic techniques like pump-probe and multidimensional approaches in nano-optics to push their spatial resolution beyond the diffraction limit and to improve their ability to address individual quantum systems.

Nano Sensing: We focus on nanophotonics-based sensing as it promises to build on the advantages of optical sensing, while overcoming its limitations by providing a high sensitivity, specificity, dynamic range, as well as the possibility for easy integration into simple and affordable devices.



» Due to current research topics, I decided to focus my studies on the field of solid state physics. With four research groups with different focuses in this field, the University of Siegen is broadly based. This offers students an attractive field of work, regardless of whether they have special interests in data analysis or want to investigate solids using challenging experimental methods. During the time of my master thesis, it was possible to collaborate with other research groups from the physics and chemistry department, which gave me a broader view of the application area of our research. «

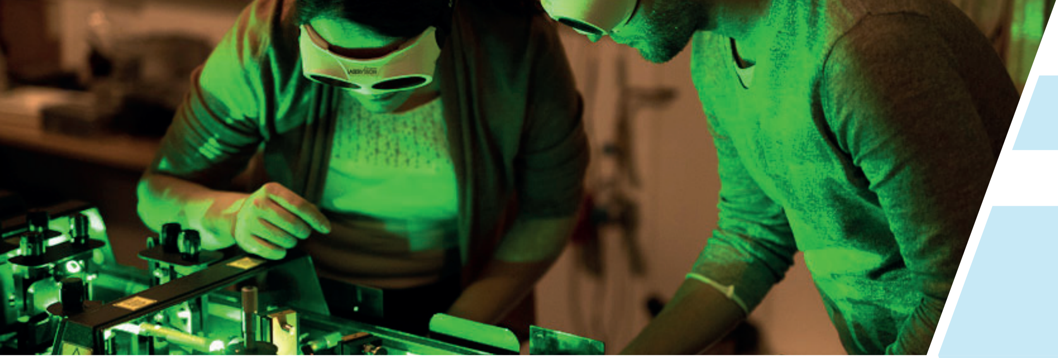
Alice Bremerich
Master of Science in Siegen, now PhD-student in Siegen

Examples of Master theses

- Optical properties of color centers in diamond nanocrystals and their coupling to plasmonic metal nanoparticles
- Electrical excitation of color centers in n-type diamond Schottky diodes
- Optical spectroscopy of epitaxially grown 2D materials (e.g. graphene)
- Vector magnetometry based on polarimetric optically-detected magnetic resonance
- Controlled creation of silicon-vacancy color centers in diamond by local ion implantation

» I started studying physics in Siegen, because I was interested in the subject, and I am from this region. I decided to stay here, because of the interesting research topics offered by the Laboratory of Nano-Optics, the freedom in the curriculum of the master course and the good atmosphere at the campus. During my master thesis I was studying the optical properties and electrical excitation of color centers in diamond, which combines the fields of quantum optics and semiconductor physics. «

Florian Sledz
Master of Science in Siegen, now PhD-student in Siegen



Further study programs offered by the Department of Physics

Master of Science (Physics)
Focus Area: Quantum Optics and Quantum Information

- admission requirements: B. Sc. in Physics or equivalent
- start: winter or summer term
- contact: Dr. Matthias Kleinmann (international.master@physik.uni-siegen.de)

This program explores the connection between quantum physics and information theory that enables novel methods of information processing (quantum cryptography, quantum computers) and the physics behind novel techniques in quantum optical experiments that allow control and manipulation of single ions or photons.

Master of Science (Physics)
Focus Area: Particle Physics

- admission requirements: B. Sc. in Physics or equivalent
- start: winter or summer term
- contact: Dr. Carmen Diez Pardos (Carmen.DPardos@uni-siegen.de)

Particle physics deals with the most fundamental questions related to the structure of matter at smallest distances, pushing the limits of our knowledge to new frontiers. The insights from particle physics also have profound implications on our understanding of cosmology, in particular on the early stages after the Big Bang.

General information for all programs

- 4 semesters
- 120 credit points (ECTS)
- language of instruction: English (certificate of proficiency required)
- international and national students

Master of Science (Nanoscience and Nanotechnology)

- admission requirements: B.Sc. in Physics, Chemistry, Electrical Engineering or equivalent
- start: winter term
- contact: Prof. Dr. Mario Agio (mario.agio@uni-siegen.de)

The master is a joint initiative of the Departments of Physics, Chemistry and Electrical Engineering. It focuses on modern aspects of the science and technology of nanoscopic systems, ranging from basic knowledge to applications and devices.

Master of Science (Quantum Science)

- admission requirements: B. Sc. in Physics, Mathematics, Computer Science, Electrical Engineering or equivalent
- start: winter term
- contact: Prof. Dr. Otfried Gühne (quantumscience@uni-siegen.de)

This program focuses on foundational and practical aspects of quantum science, ranging from basic research to applications and quantum devices. It is interdisciplinary at the border between physics, mathematics, computer science, and electrical engineering.

Living & Financial Aspects

Fees and living costs

Students of the University of Siegen are not charged tuition fees. There is a semester fee of approximately 325 € due before every semester start as part of registration. This fee includes a ticket for public transport in the region.

The estimated average costs of living are 750 € per month, including rent, health insurance, food, clothing, learning materials, phone and internet, travel expenses, entertainment, and sports. These estimated costs of living vary depending on lifestyle, type of accommodation, budget, and spending habit. Additional one-time expenses for residence permit and deposit amount to approximately 700 €.

Further information concerning fees, housing possibilities and administrative matters can be found at the website of the International Office of the University of Siegen: www.uni-siegen.de/start/international/

Funding possibilities

There are several possibilities to obtain funding for studies in Germany:

- *The German Academic Exchange Service (DAAD) offers various grants for very good foreign students who want to move to Germany. Often these programs are tailored for students from certain countries. Detailed information can be found in the database of the DAAD, which also contains stipends from other foundations: www2.daad.de/deutschland/stipendium/datenbank/en/21148-scholarship-database/*
- *Very good master students frequently work as tutors for younger students, especially when they are doing their MSc thesis in a research group.*
- *In addition, some students have side jobs to earn money. The DAAD web site provides further information about conditions and rules: www.daad.de/en/study-and-research-in-germany/first-steps-germany/side-jobs/*

School of Science and Technology
Department of Physics

Contact

For questions concerning the study program **Master of Science (Physics)** with focus on **Solid State Physics** please contact the program coordinators.

More information about the course program and the research pursued by the solid state physics groups at the University of Siegen can be found on our webpages.

Solid State Physics
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Page 15: Florian Sledz (private)

Note: This document provides a non-committal overview of the program. Legally binding information is to be found in the Book of Modules and Examination Regulations.

Status: March 2023. Subject to change.