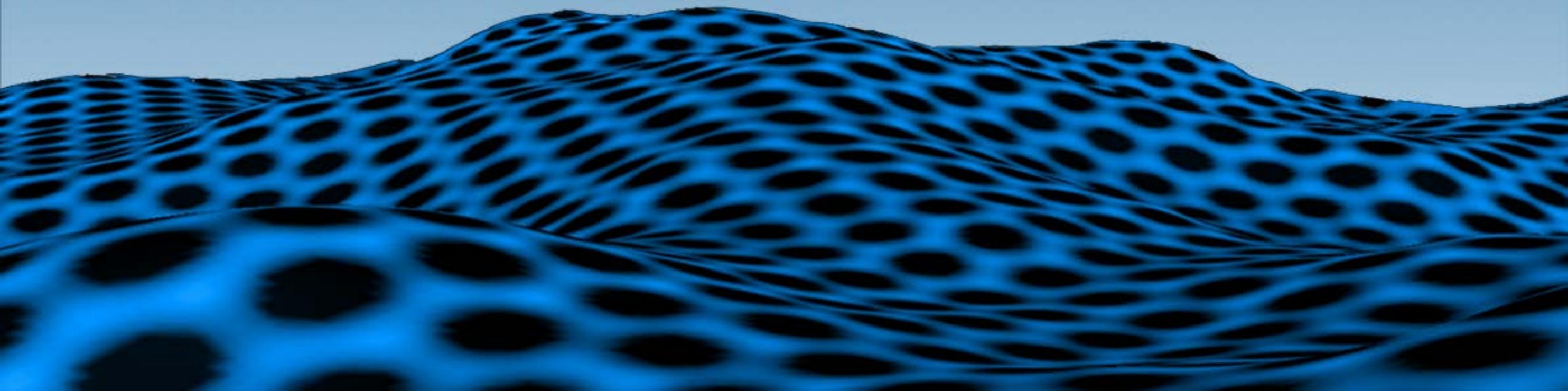


Nanoelectronics

M.Sc. in Physics, Majoring in Nanoelectronics

M.Sc. in Electrical Engineering, Information Technology and Computer Engineering, Majoring in Micro- and Nanoelectronics



Spin-Based Nanoelectronic Devices

RWTH Aachen

JARA-FIT

Bioelectronics

THz Electronics

Reconfigurable Architectures

Quantum Computing

Physics Energy-Efficient Memories

Micro- & Nanoelectronics

Forschungszentrum Jülich Electrical Engineering

Green IT

New Optical, Analytical and Manufacturing Nanotechnologies

Sensoric

Graphene-Based Electronics

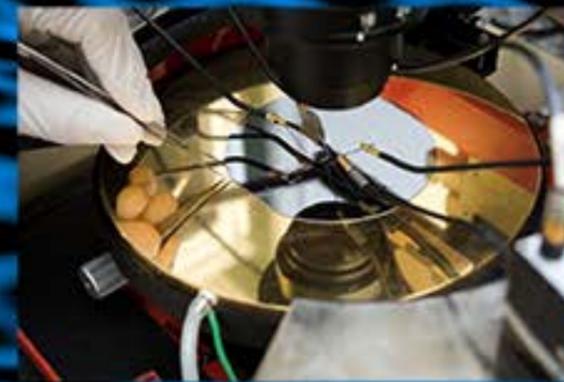
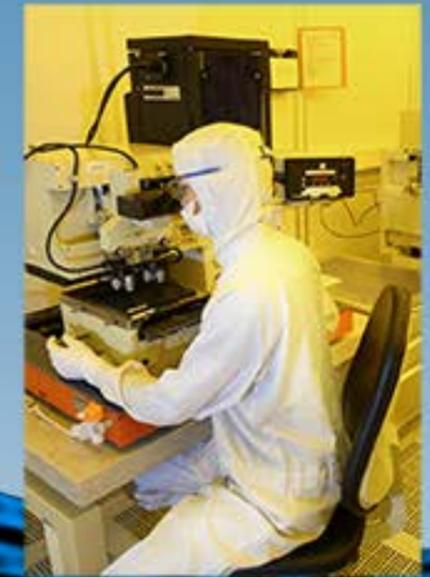
Semiconductor Nanoelectronics

Nanoionic Memories

Optoelectronics

More than Moore
Neuromorphic Circuits

Molecular Electronics



What is Nanoelectronics?

Micro- and nanotechnology are at the heart of information and communication technology. Modern microelectronic circuits exhibit an enormous complexity with minimum feature sizes on the device level as low as 20nm; and, miniaturization continues to push technological limits further and further. Additional performance improvements and an increase in functionality are expected with the integration of novel materials and radically new device concepts. This evolution is triggered by the steady demand for more functionality, higher speed and – increasingly important – for more energy efficiency. In particular, reducing power consumption will become a major technology driver because the realization of ultra low power devices and circuits will enable the exploitation of the huge technological potential of energy-autonomous systems for smart homes, health care etc.



Preparation of semiconductor wafers in the cleanroom facility for the development of nanoelectronic devices.
Picture: Forschungszentrum Jülich

and materials properties and require novel engineering approaches, in a fast-moving and expanding field.

For further reading, you may like to take a look into **"Nanoelectronics and Information Technology"** [R. Waser (Editor), Wiley, ISBN: 978-3-527-40927-3], written mainly by scientists from RWTH Aachen University and Forschungszentrum Jülich, which offers a comprehensive introduction to electronic materials and device concepts for the major areas of current and future information technology and targets at graduate students of physics, electrical engineering and information technology as well as materials science.



View into the Nano-Spintronics-Cluster-Tool, a platform for magnetism- and spintronics-related research.
Picture: Forschungszentrum Jülich

It is now also the time to lay the foundation for completely new solutions for future information technology, exploring, e.g., spintronics, molecular electronics as well as neuromorphic and quantum information processing. Moreover, hybrid approaches such as combining the biological and neurological worlds with microelectronics becomes increasingly interesting. These developments pose serious scientific and technological challenges that involve fundamental issues of nanoscale physics

Nanoelectronics provides the basis of modern information technology. Major examples include

1. high-performance computing, including supercomputers, servers, and personal computers, requiring significantly reduced power dissipation
2. mobile systems that truly integrate different services that can interact with users in a semantic manner
3. tiny systems, so-called "sensory swarms" embedded into our clothes and everyday articles to assist us; this area not only requires ultra-low power computational performance but also additional functionality, such as tactile sensor arrays, optical imaging systems, electronic "noses", and interfaces with the biological world.

Nanoelectronics in Aachen and Jülich

You are interested in studying at one of Europe's leading technical universities and you have an interest in information technology?

The master's programmes in Physics and in Electrical Engineering at RWTH Aachen University offer an application-orientated course in nanoelectronics in cooperation with the Forschungszentrum Jülich. At one of the largest interdisciplinary research centres in Europe you will have access to superior facilities during laboratory courses including the new cleanroom facility for nanoelectronics. You are given a thorough grounding in physics and electrical engineering by scientists working at both institutions and you are able to gain insights into ongoing research projects at both locations, the possible starting point for your own master's dissertation. You will also be able to exchange ideas with researchers from other fields in the extraordinary multidisciplinary research environment facilitated by the Jülich Aachen Research Alliance (JARA) and collaborative work on future information technology (JARA-FIT). JARA-FIT fosters collaboration between physicists, electrical and mechanical engineers, chemists, mathematicians, biologists and materials scientists from 32 institutes and departments of RWTH Aachen University and Forschungszentrum Jülich. Research is targeted towards a basic understanding and technical development of nanoelectronics and information technology with an emphasis on novel concepts for future energy-efficient information technology and on electronic phenomena in specific fields of energy technology.



*Super C, RWTH Aachen University.
Picture: Peter Winandy*

Your future place: in Aachen and Jülich

RWTH Aachen University, established in the late 19th century, unites tradition in excellent research and education. It is one of the top technical universities in Germany and Europe. Today, around 40,000 young people from all over the world are enrolled in about 115 degree programmes at RWTH Aachen University. Aachen itself is situated on the borders of the Netherlands, Belgium and Germany and exhibits an international flair. The city combines a rich cultural heritage with several international sports events each year and a vibrant cultural life.



*Meeting point Super C at RWTH Aachen University.
Picture: Peter Winandy*

Forschungszentrum Jülich is a member of the Helmholtz Association and is situated just 30 minutes from Aachen. Its science campus hosted in 2013 around 1300 scientists and more than 900 PhD students who work in the fields of energy and the environment as well as information and brain, developing the basis for the key technologies of tomorrow. Using world-class tools, scientists from all around the world conduct their research on the campus by means of simulation with supercomputers, unique analytical and characterization equipment, and imaging techniques for medicine and nanotechnology. Nanoelectronics research at Jülich is concentrated in the Peter Grünberg Institute, named after the 2007 Nobel laureate in physics, who discovered at Jülich the giant magnetoresistance resulting in a major breakthrough in hard disk drive technology.

Career prospects

Graduates with a major in nanoelectronics have excellent job opportunities in many areas of the semiconductor industry. It should be noted that the worldwide market for micro- and nanoelectronics has grown by 5 percent per year since 2000, and that further growth is predicted. The industrial sector already has a significant share of the world's economy (estimated 10 percent of worldwide GDP), and it will continue to rise in view of the penetration of digitalization in our everyday life, in offices or industrial production. **The job market is attractive for graduates, and it is fairly diverse. This includes the global microelectronic industry, equipment and materials suppliers as well as small start-up companies.**



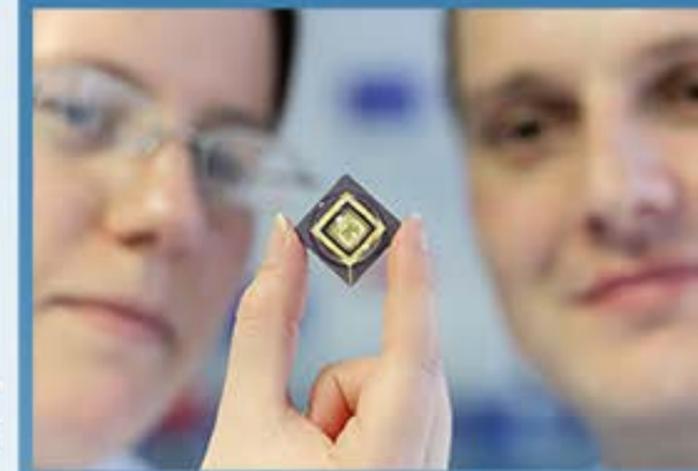
View of the thin film manufacturing tool at the Helmholtz Nanoelectronic Facility.
Picture: Forschungszentrum Jülich

Aachen is a good place for this; the regional network of research and industry in the IT-sector (REGINA: <http://www.regina.rwth-aachen.de>) and a large number of start-up companies in the greater Aachen area show the region's potential for innovation and transfer of technology. For instance, AIXTRON, a company founded by employees of the Institute for Semiconductor Technology at RWTH Aachen University in

1983 (the name is formed from the French name for Aachen, Aix-la-Chapelle and "electronics"), which is today a global player in providing deposition systems for electronic applications, such as LEDs, power electronics, and photovoltaic materials. Another example is the RWTH Aachen Campus, where the University is currently establishing a unique portfolio of services for coopera-

tion in specialist clusters giving national and international companies the opportunity to become involved on the campus with their own research and development capacities. More than 120 companies are already involved and six clusters are presently being established on Campus Melaten including a Photonics Cluster.

It should be emphasized that the field of nanoelectronics is not only limited to information technology. Nanoelectronics is also applicable to energy technology, e.g., in the field of photovoltaics or nano batteries, it holds promise for the development of new types of miniaturized sensors, integration into automation or robotics and, last but not least, the design of in vivo medical devices.



A prototype biocompatible chip made of graphene connected to living tissue. The ultimate goal is new carbon-based biointerfaces for neural implants.
Picture: Forschungszentrum Jülich

Exciting opportunities are available in many fields of application for micro- and nanoelectronics including

- telecommunications
- automation and control
- instrumentation
- biomedicine or health care
- aerospace industry
- energy conversion and storage
- environmental monitoring
- basic and applied research

Who is eligible?

Our graduate programme combines materials science and nanoscale physics with the technology of nanoengineering of devices, while students continue their professional development as a condensed matter physicist or electrical engineer. Standard requirements are a bachelor's degree in physics or electrical engineering, or in a related field such as materials science or chemistry (see page 19). JARA coordinates the special Master's course in nanoelectronics as a joint course of studies in physics and electrical engineering. Accordingly, the area of specialization can be chosen with an emphasis on electrical engineering for a

Master's degree (M.Sc.) in "Electrical Engineering, Information Technology and Computer Engineering", Majoring in Micro- and Nanoelectronics,

or with a focus on physics for a

Master of Science (M.Sc.) in Physics, Majoring in Nanoelectronics.



Main building of RWTH Aachen University.
Picture: Peter Winandy

What is the curriculum?

These Master studies follow the following general scheme. In the first year of the Master's studies students take mandatory courses as well as elective courses chosen from the many specialized courses. They are offered by the Department of Physics and the Faculty of Electrical Engineering and Informa-



Building with lecture theatres (left) and building with the Student Service Centre (right) at night.
Picture: Peter Winandy

tion Technology, including many researchers from Forschungszentrum Jülich as teachers. It is also possible to include courses from other Master's programmes such as biophysics, chemistry, computer science, mathematics, laser technology, materials science.

During the second year, students will additionally complete a Master's thesis research project. The precise form of the project depends on the research topic and is developed together with a supervisor who is responsible for the project. The students have to complete their Master's thesis work, write up their Master's thesis and give a final presentation about their research project (Master's defence colloquium).



Students in the lecture hall of the physics department at RWTH Aachen University.
Picture: Peter Winandy

Students with a strong academic performance can apply for a scholarship or can work as a research or teaching assistant. You might take part in ongoing research projects either at RWTH Aachen University or Forschungszentrum Jülich. Such a position is often a good supplement to your own degree programme and is at the same time a good preparation for a doctoral thesis.

M.Sc. in Physics

Specialization in "Nanoelectronics"

The international Master's curriculum in physics consists of six different fields. "Nanoelectronics" is one of these. The study programme of the first year is composed to equally mandatory and elective courses (see Fig. 1). The elective courses can be chosen from more than 15 specializations offered by the Department of Physics and the Faculty of Electrical Engineering and Information Technology including courses from researchers at Forschungszentrum Jülich (see Fig. 2, page 13). Furthermore, elective courses can

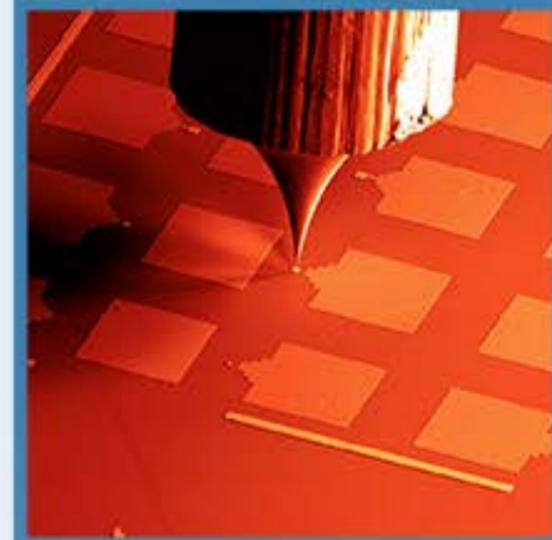
also be taken from other related Master's programmes such as computer science, laser technology or materials science. The Course Module Catalogue will give you a comprehensive insight.

(see Physics RWTH Aachen:
<http://www.physik.rwth-aachen.de/cms/Physik/Studium/Im-Studium/~dxlx/Master-s-Program-Physics/?lidx=1>)

Fig. 1: Overview of the course for the M.Sc. in Physics, Majoring in "Nanoelectronics" at RWTH Aachen University.

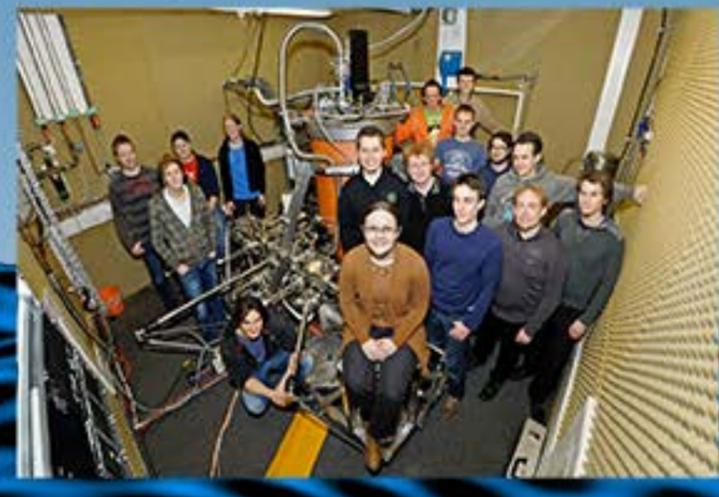
1st Semester		
Condensed Matter (10 CP)	Elective Courses (15 CP)	Novel Materials and Devices in Information Technology I (5 CP)
2nd Semester		
Laboratory Course Nanoelectronics (10 CP)	Elective Courses (15 CP)	Novel Materials and Devices in Information Technology II (5 CP)
3rd Semester		
Master's Seminar (15 CP)	Master's Practical (15 CP)	
4th Semester		
Master's Thesis and Master's Defense Colloquium (30 CP)		

Majoring in nanoelectronics includes training in state-of-the-art condensed matter physics. Special emphasis is given to the relationship between quantum mechanics on the microscale and macroscopically measurable quantities. In a link to electrical engineering you will learn the basic principles and technology used for the design of information-processing components and storage devices. These fundamental fields are complemented by a variety of elective courses.



Scanning probe microscopy of semiconductor nanostructures. Picture: Forschungszentrum Jülich

In the field of nanoelectronics you have the chance to design your study programme depending on your personal interests and professional aims.



Low temperature scanning probe microscope at RWTH Aachen University with Ph.D. and Master's students. These microscopes with high energy resolution, complex electron and spin systems can be used to study matter down to the atomic scale such as graphene, which is a sheet of carbon just one atom thick. Picture: Peter Winandy

Note that...

...For further information about the Master's programme in physics we recommend to contact the academic adviser directly:

Dr. Stefan Roth

Sommerfeldstr. 14, Room 26 C 204, 52074 Aachen
 Phone: +49 241 80 23688
 Email: studienberater@physik.rwth-aachen.de

<http://www.physik.rwth-aachen.de/cms/Physik/Studium/Kontakt/~dxng/Fachstudienberatung-Bachelor-und-Master/>

Laboratory Course

The Master's Laboratory Course Nanoelectronics provides a unique opportunity to become familiar with recent research projects in your chosen field. The practical part of your study programme consists of three experimental blocks. While experimental blocks A and C are held at different institutes at RWTH Aachen, experimental block B takes place at Forschungszentrum Jülich. As part of the JARA-FIT Spring Course "Nanoelectronics" at Forschungszentrum Jülich you will deal for example with transmission electron microscopy, the preparation of multifunctional oxide layers or quantum transport in nanostructure semiconductors. The nanoelectronic facilities at the Peter Grünberg Institute in Jülich supply exceptional facilities – especially a cleanroom equipment - for a practical course very close to current research activities.

Fig. 2: Study courses for M.Sc. in physics, Majoring in nanoelectronics.

LECTURES

- Condensed Matter
- Novel Materials and Devices in Information Technology
- Spintronics
- Semiconductor Technology & Characterization
- Technology of Extreme Ultraviolet Radiation
- Nanoelectronics Devices
- Electronic Measurement
- Silicon-Based Sensors and Actuators
- Compound Semiconductor
- VLSI Architecture for Digital Signal Processing
- Robotics and Man/Machine Interaction
- Optical Communications: Devices and Structures
- Seminar Physics in Nanostructures
- Carbon Nanoelectronics
- Laboratory Nanoelectronics
- Physics of Nanostructures
- Oxide Thin Films for Information Technology
- Quantum Simulations of Carbon Nanotube and Graphene
- Nanoribbon Field-Effect Transistors

In the context of experimental block A at the Department of Physics you will be introduced to, e.g., atomic force microscopy, quantum transport, superconductivity and SQUID together with photoluminescence. Experimental block C is performed at the faculty of Electrical Engineering and Information Technology. Here you will have the opportunity to experience several laboratory stations on the subject "From Material to Device".

Did you know that...  ...JARA-FIT organizes practical lab courses at the Peter Grünberg Institute, Forschungszentrum Jülich?

The lab course introduces you to current research topics of Nanoelectronics and gives you the opportunity to use the top-level laboratory research equipment. After introductory lectures, you are able to perform one experiment per day in small groups.

See: www.fz-juelich.de/pgi/nanoelektronikpraktikum (in German)

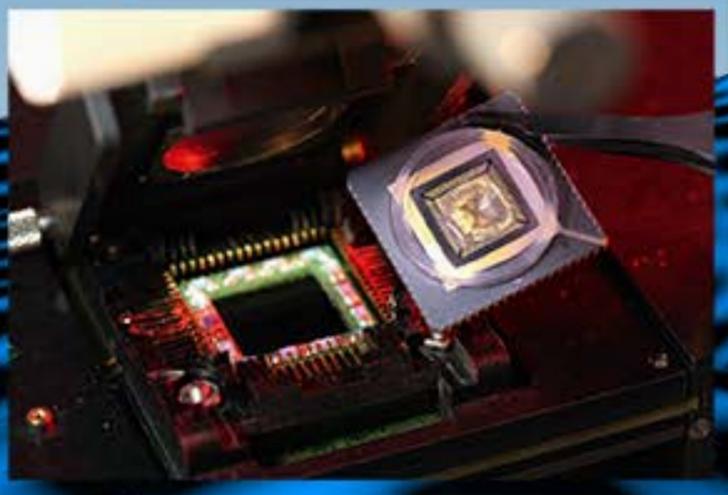
Impressions from JARA-FIT practical course in nanoelectronics. Students have the opportunity to take part in current research projects. Pictures: Forschungszentrum Jülich



Specialization in "Micro- and Nanoelectronics"

The design of micro- and nanoelectronics systems, technology and applications is becoming more and more closely interlinked. The Master course takes these requirements into account.

The course in micro- and nanoelectronics for electrical engineers provides a broad field of work with excellent job opportunities in the electronic device industry. Micro- and nanoelectronics is considered to be the key technology for technical innovations with several applications in the production and storage of energy as well as materials science and engineering technology. Students majoring in micro- and nanoelectronics obtain a well-founded knowledge of key research areas such as micro- and nanotechnological device fabrication, materials and devices, system and circuit design as well as VLSI structures.



Graphene is one of the most exciting electrical materials researchers work on. It will be used for future chip- and nanotechnologies. Picture: Forschungszentrum Jülich

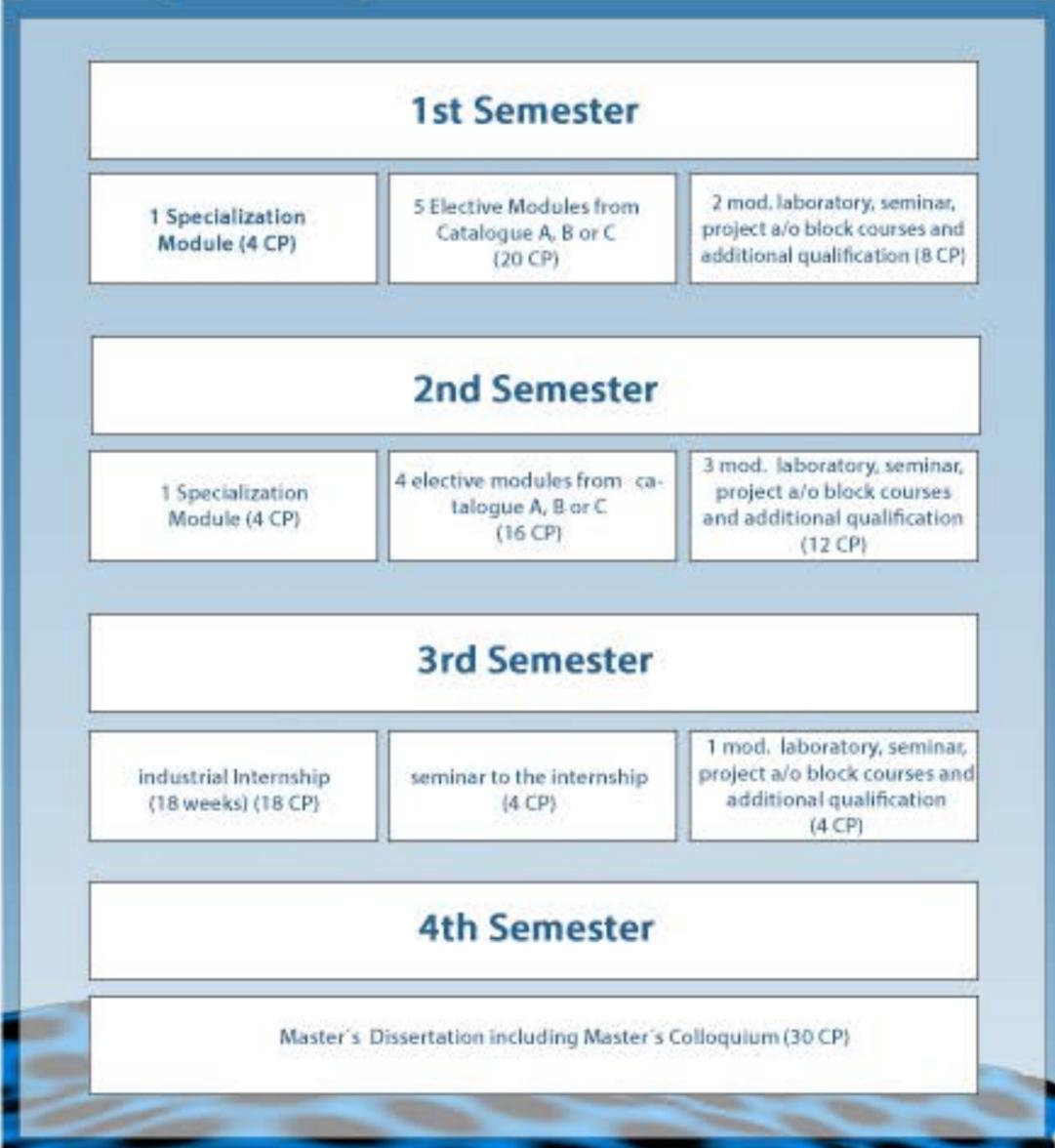


Fig. 3: Overview of the course for the M.Sc. in Electrical Engineering, Majoring in "Micro- & Nanoelectronics" at RWTH Aachen University.



Picture: Peter Winandy

For this purpose you can choose from a variety of subjects. Classes are offered, for instance, in solid-state technology, nanoelectronic devices, micro-system technology, photonics, novel materials and devices, VLSI-CMOS design and OLED. Areas of research may be tunnel field-effect transistors, graphene, photovoltaics, silicon photonics, organic semiconductors or GaN-Devices.

Note that...
 ...For further information about the Master's programme in micro- and nanoelectronics we recommend to contact the academic advisers directly:
 Dipl.-Ing. Martina Dahm, Dr.-Ing. Pia Müller,
 Dipl.-Math. Ingrid Reißel
 Mies-van-Rohe-Straße 15, 52074 Aachen
 Phone: +49 241 80 27572
 E-Mail: studienberater@fb6.rwth-aachen.de

Specialization in "Micro- and Nanoelectronics"

The studies in micro- and nanoelectronics consist of three module fields: "Devices and Technology" (A), "Circuit and Architectures" (B) and "Systems and Applications" (C). Besides fundamental courses in materials, sensors, actuators, circuit design, VLSI architectures and computer arithmetic plus high-frequency systems, emphasis is given to a number of microelectronic applications. The courses of the three module fields mentioned above are taken in the first and second terms of the Master's programme while the third term is reserved for block courses, seminars, non-technical lectures and an industrial internship. (see Fig. 4)

A: DEVICES AND TECHNOLOGY	B: CIRCUITS AND ARCHITECTURES	C: SYSTEMS AND APPLICATIONS
<ul style="list-style-type: none"> Festkörpertechnologie Neue Materialien und Bauelemente in der Informationstechnik Siliziumbasierte Sensor- und Aktorsysteme Electronic Noise In Device and Circuits III-V-Halbleiter Elektronische Messtechnik Optische Telekommunikation Numerische Bauelementsimulation Oxidische Dünnschichten für die Informationstechnik 	<ul style="list-style-type: none"> VLSI-Architekturen für die digitale Signalverarbeitung Analog- und Mixed-Signal-Elektronik Computer Arithmetik HF-System- und Übertragungstechnik Quantum simulations of carbon nanotube and graphene nanoribbon field-effect transistors 	<ul style="list-style-type: none"> Hochfrequenztechnik Digitale Sprachverarbeitung Multimedia Communication Systems Digitale Bildverarbeitung Robotik und Mensch/Maschine Interaktion Medizintechnische Systeme HF-System- und Übertragungstechnik Basic techniques in computer graphics Advanced Control Systems Power Electronics - Control, Synthesis and Applications Elektrische KfZ-Bordnetzkomponenten Elektrische Energie aus regenerativen Quellen

Fig. 4: Course provisions of the study courses M.Sc. in Electrical Engineering, Information Technology and Computer Engineering, majoring in Micro- and Nanoelectronics.

Students have a wide range of options within the course. In module A (Devices and Technology) they must obtain at least 8 and at most 24 credit points. The same applies to the module B (Circuits and Architectures). Solely module C (Systems and Applications) is restricted to 4 credit points.

Note that...
... lectures in electrical engineering may still be held in German while the accompanying materials (i.e. slides) are generally in English.

As a whole, 36 credit points must be obtained. Specifically designed laboratory courses are mandatory for modules A and B. Fig. 4 gives a summary of the Lectures.



Students in one of the several lecture theatres at RWTH Aachen University. Picture: Peter Winandy

Did you know that...
...JARA-FIT organizes practical lab courses at the Peter Grünberg Institute, Forschungszentrum Jülich?
The lab course introduces you to current research topics of Nanoelectronics and gives you the opportunity to use the top-level laboratory research equipment. After introductory lectures, you are able to perform one experiment per day in small groups.
See: www.fz-juelich.de/pgi/nanoelektronikpraktikum (in German)



Impressions from JARA-FIT practical lab course at Forschungszentrum Jülich. Pictures: Forschungszentrum Jülich

How to apply

For both Master's programmes, physics and electrical engineering, a Bachelor degree is required either in physics or in electrical engineering. Other Bachelor's degrees such as information technology, computer engineering, material science or chemistry may be considered, but additional courses may be required. The examination regulations for the Master's programmes provide further information about the requirements. In addition, for the Master's programme of Electrical Engineering, Information Technology and Computer Engineering German language skills equivalent to C1 level of the Common European Framework of Reference for Languages are needed. For the Master's in physics, which is taught in English, English language skills are required. Evidence for the English language skills can be provided with a TOEFL 80, a TOEFL 550, an IELTS 6.0 attestation or a Certificate of Advanced English (Cambridge ESOL). Students with a Bachelor's degree from a university in the UK, Australia, Ireland, Canada, New Zealand or the USA do not have to furnish proof of their language skills.



Your application is the first step before you can start your M.Sc. in Electrical Engineering, Informations Technology and Computer Engineering, Majoring Micro-and Nanotechnology or M.Sc. in Physics, Majoring In Nanoelectronics. Picture: Peter Winandy



Students at Super C RWTH Aachen University
Picture: Peter Winandy

The modalities and terms of application for your Master's in physics or electrical engineering vary depending on your nationality or the country where you obtained your Bachelor's degree. As a foreign student (EU and Non-EU) we strongly advise you to contact the International Office for further information about your application.

Nationality	Application Deadline for Winter Semester	Application Deadline for Summer Semester
German	15 July of the same year	15 January of the same year
EU/EEA Countries	15 July of the same year	15 January of the same year
Non-EU/EEA Countries	1 March of the same year	1 September of the previous year

Applications via:
www.rwth-aachen.de/ioam (Internationals)
<https://zul-fm.campus.rwth-aachen.de> (Germans)

Contact Information

For further organizational information about enrolment please contact either the Registrar's Office or for foreign applicants the International Office (See page 21).

 Did you know...

Registrar's Office
 SuperC, Templergraben 57
 52056 Aachen
StudSek@zhv.rwth-aachen.de

Opening hours:
 Monday, Tuesday, Thursday, Friday: 8 am to 12:30 pm
 Wednesday 1 pm to 4 pm

Students at Super C RWTH Aachen University
Picture: Peter Winandy

International Office

The International Office of RWTH Aachen University offers you several services for a successful start in Aachen, e.g. an orientation programme, assistance with formalities after arrival or guided tours of Aachen and of our university. Foreign students can participate in the **Buddy Programme** or take part in the orientation days. See more about the **Info-Service Center (ISC)** at the International Office on:

Note that...
...RWTH Aachen University offers several services for foreign students which help you to get off to a good start.
For more information visit the website of the International Office at RWTH Aachen University:
<http://www.rwth-aachen.de/international>
Email: international@rwth-aachen.de

Master's College

Be smart - have a smooth study start!

Master's degrees in Germany require an undergraduate training that enables students to follow lectures at a very advanced and specialized level. Especially for these students, the Department of Physics and the International Academy, an institution for international education attached to the university, have developed a new Master's entry programme. This innovative programme includes scientific guidance, involvement in research and laboratory experiments, as well as intense social support especially for international students.

(<http://www.masterscollege.rwth-aachen.de/>)



Get together and keep in touch with other students. At Super C RWTH Aachen University. Pictures: Peter Winandy



Picture: Peter Winandy

Be Buddy Programme...

...is an informal mentoring programme initiated by the International Office of RWTH Aachen University, which aims to enable newly enrolled international students to adjust to university life and living in a new city, and to meet, mix with, and learn from other RWTH students.

For more information visit:
<http://www.rwth-aachen.de/bebuddy>



JARA-FIT Practical Lab Course

Felix, student at the University of Würzburg

Why are you interested in nanoelectronics and/or what was your motivation to enter the field?

"I wanted to take part in the ever accelerating development of computer technology. I think it is important to improve today's status quo and provide alternatives to existing technologies, in order to reduce the need for energy or to increase computing power and speed."

Why is the Master's Course in nanoelectronics at Aachen attractive for students?

"The Forschungszentrum Jülich and RWTH Aachen provide a great infrastructure through the JARA-FIT programme. Aachen is a very nice city, not as big as Cologne or Munich, but it still has a vibrant city life."

Mehmet, student at the University of Stuttgart

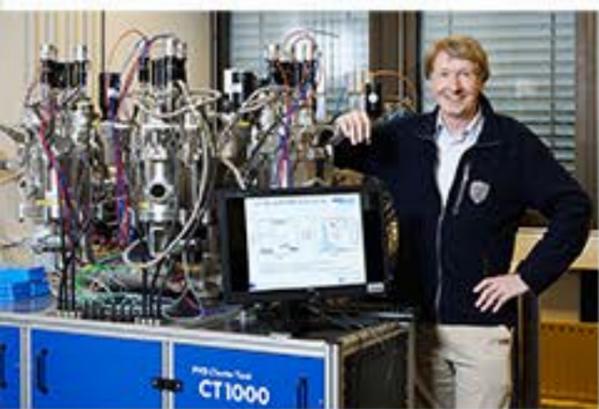
Why are you interested in nanoelectronics and/or what was your motivation to enter the field?

"The technology of the future will be built up by nanoelectronics devices. The developments in this field will easily find applications i.e. in biosciences, industry etc. Moreover you can also get a feeling for quantum mechanics and observe the basic laws of quantum physics. Besides you can also get a deep understanding of basic physical laws and may contribute the development of new theories."

Why is the Master's Course in nanoelectronics at Aachen attractive for students?

"The collaboration between the University of Aachen and Forschungszentrum Jülich is the first important point to attract students to the programme. After the Master's programme, you can do your Ph.D. at Jülich with first class scientists and research opportunities and you may end up becoming a prominent scientist in this area of research."

What's new in the roadmap for semiconductors?



Rainer Waser, born in 1955, studied chemistry at Technische Universität Darmstadt. He worked for eight years in industry at the Philips Research Laboratories. In 1992, he was appointed professor in the Faculty of Electrical Engineering and Information Technology at RWTH Aachen University. Since 1997 he has also been the Director of the Peter Grünberg Institute at Forschungszentrum Jülich. With a high-calibre global network, Waser is one of the most cited representatives of his field and is highly respected as a lecturer and mentor for early career researchers. In 2014 he received the Leibniz Prize of the Deutsche Forschungsgemeinschaft (DFG, German Research Foundation), one of Germany's most prestigious research prizes.

You have contributed to the International Technology Roadmap for Semiconductors (ITRS). Can you highlight a few driving trends which will govern the emergent devices and materials for IT?

Current highlights in the emerging device section of the ITRS are the redox-based resistive switching effects mentioned before, magnetoresistive memories based on spin-torque transfer, 2-D channel materials for field-effect transistors such as graphene or inorganic materials such as MoSe₂, dedicated molecules with electronic functionalities, and – in the long run – quantum information technology. Students may find it both fascinating and challenging that nanoelectronics represents an interdisciplinary field in which knowledge of solid-state physics, chemistry and materials science, as well as of electrical engineering and information theory merges.

Nanoelectronics is not only interesting for information technology. There are other areas where the field of nanoelectronics plays a role. Can you give some example of exciting opportunities?

The microscopic processes of redox-based resistive switching of metal oxide memory cells (ReRAM cells) reveal a complex and highly fascinating interplay of ion motion on the nanoscale, changes of the local electronic structure, electronic transport phenomena, and high-field effects, and they show similarities to surface reactions during electrocatalytic processes at similar metal oxides which are utilized for sensors or energy conversion (“power-to-gas”).

You are an electrochemist by training. Now you are professor in the faculty of electrical engineering and information technology. How do electrochemistry and information technology come together and fit together?

Electrochemistry is just another expression for the physics of electron transfer reactions and ionic motion at interfaces. And the configuration of ions and atoms represents an interesting state variable in information technology, which is particularly suitable for non-volatile memories or for synaptic weights in artificial neurons.

Why be an engineer and a physicist at the same time?

Christoph Stampfer, born 1977, studied physics and electrical engineering at Vienna University of Technology, Austria and received his PhD degree from the Department of Mechanical and Process Engineering at ETH Zürich, Switzerland. After a postdoc stay at the Laboratory of Solid State Physics at the ETH he joined JARA-FIT and became junior professor at RWTH Aachen University and Forschungszentrum Jülich. Recently, he was appointed head of the 2nd Institute of Physics A at the Faculty of Mathematics, Computer Science and Natural Sciences at RWTH Aachen University. His field of interest is carbon-based quantum electronics and he is a member of the European Graphene Flagship consortium.



Graphene, a hexagonal lattice of carbon, is considered one of the most promising materials for future IT applications. What makes graphene such a promising material?

Graphene is the very first two-dimensional material and offers a unique combination of very useful properties. Graphene is a highly conductive membrane, which is at the same time optically transparent and mechanically ultra-stable and flexible. This combination makes graphene very interesting for a large number of applications such as foldable touch screens, flexible electronics and high frequency transistors.

In the course of your studies and your career you have worked in physics, electrical engineering and mechanical engineering. Can you give us an example of how these fields come together and offer new perspectives?

Having a background in these different fields helps me to design new types of experiments: for example micromachining techniques can be used to investigate the interesting electromechanical properties of graphene, both from the fundamental and the technological point of view. In general, research in applied nanotechnology is becoming more and more interdisciplinary, covering many different aspects ranging from fundamentals of mesoscopic physics and quantum-electronic device concepts to advanced nanofabrication technologies. This makes a broad background important and extremely helpful. Applied graphene research is a very good example of this, since interdisciplinarity helps to move fast.

How can young students contribute to graphene research?

The highest quality graphene samples are still fabricated by a simple technique based on Scotch tape and exfoliation of graphite. Students can learn this technique within an afternoon allowing them to quickly make interesting graphene samples to study fundamental questions.



Joachim Knoch, born 1972, studied physics at RWTH Aachen University and Queen Mary, University of London (UK). He received the MS and PhD degrees from RWTH Aachen University and has worked as a scientist at Massachusetts Institute of Technology (US), Forschungszentrum Jülich and IBM Zürich Research Laboratory (CH). He became professor of electrical engineering at TU Dortmund University in 2008, where he mainly worked on electronic transport in nanowire/tube transistors. In April 2011, he was appointed head of the Institute of Semiconductor Electronics (IHT) at the Faculty of Electrical Engineering and Information Technology of RWTH Aachen University.

You are a physicist by training, you have worked at such fascinating places as MIT in Boston or IBM Zurich Research Laboratory and are now professor in Aachen for Semiconductor Technology. With your experience, what do think are the major demands on scientists when they want to work on future nanoelectronic chips.

Working on nanoelectronics systems is truly interdisciplinary since it inherently implies that a scientist must have a deep understanding of the physics, engineering and materials science aspects of the field. This is exactly why this field of research is so fascinating: you explore fundamental physical phenomena but at the same time you can come up with devices that are real, that work at room-temperature and might even make it into a product.

One of the trends in semiconductor technology is that the power consumption of highly integrated circuits is one of the major issues preventing a further increase in integration density and clock speed. Could you give us some insight into promising solutions studied at Aachen?

Together with JARA-colleagues at Forschungszentrum Jülich we study band-to-band tunnel transistors that potentially allow a substantial reduction of the power consumption of integrated circuits. Such green IT is very desirable to increase the energy efficiency of our information and communication technology. In addition, ultra-low power is of paramount importance for mobile devices and facilitates completely novel applications such as energy-autonomous systems for patient surveillance or smart homes.

Bert Voigtländer, born in 1958, studied physics in Cologne and at RWTH Aachen University. He received his PhD in the field of surface science from Aachen. Subsequently, he was postdoctoral fellow at the IBM Th. J. Watson Research Center in Yorktown Heights, USA. Since his return to Germany, he works as principal investigator at Forschungszentrum Jülich and is adjunct professor at RWTH Aachen University. His research field is the microscopy of semiconductor nanostructures using scanning probe microscopy. In order to go beyond imaging and to perform electrical measurements at nanostructures, his approach is to use several scanning probes as contacts. This idea gave rise to a new kind of nanomotor, the KolaDrive, which is the heart of the multi-tip microscopes available from the recently founded spin-off company mProbes.



You devised the nanoelectronics lab course at Forschungszentrum Jülich. Can you explain the idea of the course?

The idea of the nanoelectronics lab course is to bring students into contact as early as possible with real research experiments used by Jülich JARA-FIT scientists for their research.

You founded a company based on your research. Can you explain what opportunities young physics students have today using the example of your company?

In addition to focusing attention on research results, students can also direct their attention to the (often unique) technology used to achieve these research results. Starting from this awareness of technology, it is important to identify the potential of the technology for other application fields. Ultimately, this can lead to the founding of a spin-off company, as was the case for us.

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Central Building RWTH Aachen Campus
Picture: Peter Winandy

RWTH Aachen University is one of Europe's premier educational and research institutions. RWTH Aachen University has an outstanding reputation in research and education, especially in both technological/engineering sciences and natural sciences. In national and as well international rankings RWTH Aachen University has top positions for its courses. Every year, Wirtschaftswoche (one of the most renowned business magazines in Germany) consults about 500 human resources officers about the quality of graduates and the recruitment strategy for their own company. In 2013 only RWTH Aachen University reached the first place in multiple fields of study: Electrical and Mechanical Engineering, Business Administration and Engineering together with Natural Sciences.

Becoming one of the around 33.000 students at RWTH Aachen University opens up excellent opportunities for internships and jobs in leading national and international companies, especially in the high-tech industry (regional and nationwide research partners are e.g. IBM, Siemens, Intel, Bosch and Philips). Participation in the EU-funded FET-Flagship project "Graphene" is the latest example of the outstanding research at RWTH Aachen University, especially in physics and electrical engineering.



Students life at RWTH Campus - Super C
Picture: Peter Winandy

As one of the largest interdisciplinary research centres in Europe, Forschungszentrum Jülich provides an excellent infrastructure for research in science and technology. Jülich is a member of the Helmholtz Association and works with the best partners in science and industry to develop and enhance key technologies. Forschungszentrum Jülich does not only use its infrastructure and results for its own work but makes them available to the science community. In association with RWTH Aachen University Forschungszentrum Jülich hosts the Ernst Ruska-Centre (ER-C), which provides powerful electron microscopes. Furthermore, the Helmholtz Nanoelectronic Facility comprises a cleanroom environment where Master's laboratory courses take place every year.



The Helmholtz Nanoelectronic Facility, the new cleanroom facility at the Forschungszentrum Jülich, from above.
Picture: Hans Wingers
Dr. Stefan Trelenkamp



Picture: Forschungszentrum Jülich

During your studies, the laboratory courses in the Helmholtz Nanoelectronics Facility and the Peter Grünberg Institute at Forschungszentrum Jülich will be highlights. During the nanoelectronics spring course several experiments related to ongoing research projects are performed with the students. Examples are electrical characterization of a Si-device, quantum transport in semiconductor nano-structures or redox-based non-volatile storage devices. Furthermore, the facilities of the Peter Grünberg Institute contribute exercises in transmission electron and spectral microscopy.