Elitenetzwerk Bayern

MAOT

SAOT

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# ELITE MASTER PROGRAMME &

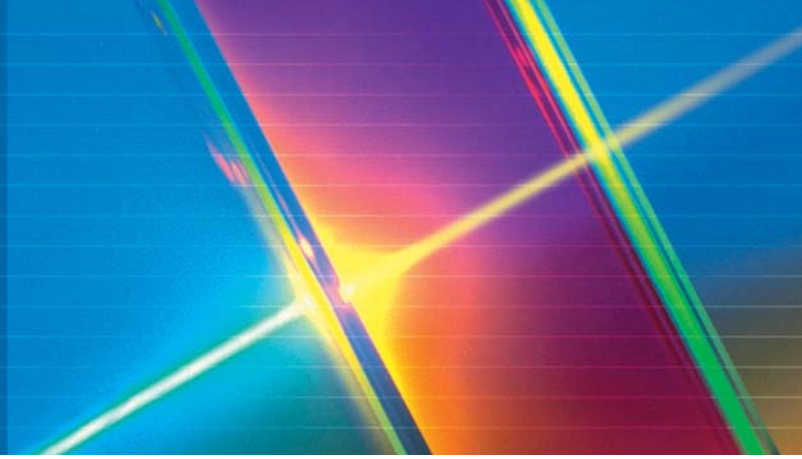
Doctoral Programme in

# ADVANCED OPTICAL TECHNOLOGIES

Friedrich-Alexander-University of Erlangen-Nuremberg

www.aot.uni-erlangen.de

Friedrich-Alexander-Universität Erlangen-Nürnberg



# WELCOME

The Friedrich-Alexander University of Erlangen-Nürnberg is one of the leading centres of excellence for optics and optical technologies in Germany and the world.

In 2006 the SAOT doctoral programme in optical technologies was first established in Erlangen within the framework of the Excellence Initiative of the German Federal and State Governments. The University of Erlangen-Nürnberg was chosen on the basis of its international reputation and scientific expertise in optics and optical technologies.

In January 2009 the new Max Planck Institute for the Science of Light was founded in Erlangen – adding to the concentration of excellence in the field.

Since 2007 the Master's in Advanced Optical Technologies (MAOT) programme has provided entry into this exciting world of the science and the application of light and optical technologies for those with a Bachelor degree.

The integrated MAOT and SAOT programmes offer extensive and high quality research and education opportunities:

- ➜ for high potential students
- ➜ in a key field of future science and technology
- ➜ by experts from engineering, physics and medicine.

Qualifications in optical technologies available at the University range from BSc to doctoral degree (PhD) level in combination with a range of related disciplines.

Alternatively, students can attend just the MAOT programme to gain a master degree or use the programme as the beginning of a doctoral research degree or further qualification.

This brochure provides information on topics that are common to the MAOT and SAOT programmes and more detailed information about the Master's degree. The section 'MAOT & SAOT' describes the integration of both programmes.

## INTERDISCIPLINARY

An interdisciplinary approach is at the heart of the MAOT and SAOT programmes which goes far beyond usual cooperation within universities. The new initiatives bring together researchers working on similar subjects who have not previously been linked.

## INTERNATIONAL

The MAOT and SAOT are international programmes. All lectures are given in English. Although German language skills are not required, language courses are offered. Regular lectures are supported by workshops and seminars with leading international experts to provide more in depth knowledge of certain topics.

## ACADEMIC EXCELLENCE

As an elite programme, the MAOT offers and demands more than other programmes. The graduates are awarded a **'Master of Science with Honours'** as a sign of the high quality of the programme.

## FUNDING

MAOT is funded by the Elite Network of Bavaria, an initiative of the Bavarian State Ministry of Sciences, Research and the Arts (www.elitenetzwerkbayern.de).

# OPTICAL TECHNOLOGIES


Optical technology is a key to scientific and industrial development in the 21st century. A decade ago we left the 'century of the electron' with outstanding discoveries and great scientific achievements by brilliant researchers. The forthcoming focus on the photon and its application gives rise to new challenges. The **'century of the photon'** has started with exciting opportunities for researchers who are ready to face the challenges.

Light is everywhere and so is optical technology. It is found in every household, in computers, cameras and cables. Lasers in CD players and LEDs in many everyday devices are just some of the most well known examples. Numerous uses of optical technology for purposes of measurement and production can also be found in hospitals and in industry. For example, it is used in the printing industry, in optical fibres and PS systems. In the development and production of cars, air planes and space shuttles optical technologies also play a major role.

The German Federal Ministry of Education and Research says:

**'Optical technologies stand for growth and economic success (...). This means competitiveness, economic growth and employment.'**

In the last five years or so, rates of turnover in the optical industry worldwide increased annually by more than 10%. A further increase of about 7% per year is expected.

Statistics show that the average level of qualification of people working in the optical industry is particularly high. About twice as many employees as in other industries have a university degree. The investment in research is twice as high as in other areas.

This means, firstly, that a good academic qualification is indispensable for a career in the optical industry, and, secondly, that people with higher level qualifications have better prospects for a successful career than in other industries.

Germany is a centre of expertise for optical technologies. The country not only has a very well developed infrastructure at universities, research institutions and industry tailored to the needs of fundamental research in and application of optical technologies, it has also a long tradition of excellence in directly related subjects, such as physics, manufacturing or electronics. Germany is furthermore generally known for the quality of its training for scientists and engineers.

A large number of German companies rank among world leaders in the optical industry field. Consquently, Germany is a very good place to launch a career in the industry after successfully completing a master's or doctoral degree specialising in optics and optical technologies at the University of Erlangen-Nürnberg.

# ORGANISATION

## TEACHING IN ALL DISCIPLINES

The programme integrates lectures and seminars from the departments of physics, electrical engineering, manufacturing engineering, quality management, computer science, engineering thermodynamics, material sciences and medicine. The Max Planck Institute for the Science of Light is also involved in the programme.

Further institutions from outside the University, such as the Bavarian Laser Centre and the Fraunhofer Institute of Integrated Systems and Device Technology, provide additional professional support (more information about partners can be found on the website).

## COURSE STRUCTURE (4 SEMESTERS)

**First Semester**

| Fundamentals | Physics or Engineering / Medicine |
|---|---|
| Key qualifications | |

sollte man hier auch „Semester One“ usw. schreiben?

**Second & Third Semester**

| Key qualifications | | | |
|---|---|---|---|
| **Topic 1** | **Topic 2** | **Topic 3** | |
| practical course<br>Subject 1 | Subject 1<br>practical course | Subject 1<br>Subject 2 | Project report |
| Subject 2<br>Subject 3 | Subject 2<br>Subject 3 | practical course<br>Subject 3 | Internship |

**Fourth Semester**

MASTER'S THESIS

## SEMESTER ONE

Students start with the **fundamentals**. Students with a degree in engineering learn more about physics and students with a degree in physics learn more about engineering. All students get an introduction to the fundamentals of optical technologies and of medicine.

Training in **key qualifications**, such as presentation and communication skills, takes place from the first to the second semester.

At the end of semester one, students choose three out of six topics to study in semesters two and three. The topics are described from page 14 onwards.

## SEMESTERS TWO & THREE

Each topic programme combines lectures with practical courses. A project report is required for one topic. An **internship** at a research institution provides practical experience.

## SEMESTER FOUR

Semester four is dedicated exclusively to the **master's thesis**, which focuses on one of the six topics.

## SUPPORT

- Courses are taught in English to groups of 10 -15 students.
- Lectures are adapted to the needs of students.
- Facilities for individual or group work are provided in the MAOT/SAOT building.
- Tutors provide extensive support in the research field.
- The MAOT office helps with all administrative issues.

# ENTRY REQUIREMENTS


## APPLICATION

The MAOT is part of the Elite Network of Bavaria. To guarantee the level of excellence, there are particular application requirements:

- a good Bachelor degree or comparable qualification in physics or a relevant engineering subject;
- two academic references (letters of recommendation);
- a statement outlining individual reasons for applying to the programme and the applicant's aims during and after the MAOT programme;
- evidence of good English skills;
- an interview with representatives of the MAOT admission committee (by telephone for foreign students)

## PROCESS

(1) Prospective students complete the application form on the MAOT website. Form is sent via e-mail with university certificates (including transcripts) as scanned documents.
(2) After the first evaluation applicants may be asked for additional documents and have an interview with MAOT representatives.
(3) The MAOT admission committee then decides whether an applicant will be accepted onto the programme.
(4) Successful candidates receive an official letter of acceptance as an MAOT student from the University administration.

## FEE

There is no fee for the programme. Students pay only the regular University fee of about € 550 per semester.

## STUDY

The programme takes two years to complete. After a first semester of foundation courses, students proceed by selecting three topics out of six. The students have to gain a total of 120 ECTS points (European Credit Transfer System) as illustrated in the diagram below:

| | | |
|---|---|---|
| First to third Semester | written and oral exams, presentations, reports | 72.5 ECTS |
| | one project report | 5 ECTS |
| | three practical courses in University, one internship | 17.5 ECTS |
| Fourth Semester | MASTER'S THESIS | 30 ECTS |

There are regular meetings between the students and MAOT tutors during the semester. The students can also attend courses for SAOT members (see following page), can benefit from integration into top-level research at MAOT/SAOT partner institutions or take language and skills courses in English or German.

# MASTER'S AND DOCTORAL PROGRAMMES


In a knowledge-driven world, good academic qualifications are of increasing importance. In order to meet the challenges of our time, society needs highly qualified people to develop innovative solutions to new or existing unsolved problems.

Ideal solutions might appear to be simple at the end of the day but the path to finding them is becoming longer and harder. The ability to pursue this path requires high levels of scientific knowledge and skills. In many cases, a master's degree is simply not enough.

Therefore, the University of Erlangen-Nürnberg offers graduates of MAOT the opportunity to continue their studies in the field optical technologies. MAOT graduates are encouraged to proceed to the doctoral programme 'Erlangen Graduate School in Advanced Optical Technologies' (SAOT).

The University has an integrated, international approach to research and training on the master and doctoral programmes. A relevant bachelor degree programme is, of course, also available at the University of Erlangen-Nürnberg. This makes Erlangen particularly attractive to both foreign students and German students who seek for a national alternative to a comparable international programme.

The MAOT and SAOT master's and doctoral programmes share the same partnership institutions and also the topics in research and teaching. MAOT courses take place in the building which houses the SAOT administration, important SAOT research groups and new SAOT laboratories. MAOT and SAOT students learn together in courses and work together in research groups in the labs of the SAOT institutions.

## INVOLVEMENT IN THE SAOT GROUP

MAOT students or graduates can share in a range of SAOT activities:

- SAOT provides **funding** for doctoral students in optical technologies. MAOT graduates with good grades are given preference for these scholarships.
- MAOT students who formally meet the requirements for doctoral studies in Germany and plan to proceed to a PhD at the SAOT can apply for small grant from the SAOT.
- SAOT members can apply for **resources** for their research projects and receive special **training offers**. MAOT graduates are preferred candidates for SAOT membership after finishing their master's degree and as MAOT students they can already attend SAOT courses or work in doctoral research groups.
- SAOT and MAOT are located in the same **'Optics Building'** at the University campus which has its own new optical laboratories. MAOT students have access to all research facilities.
- SAOT supports junior and guest **professors** and sponsors an additional SAOT **professorship**. MAOT students can apply to work as assistants in their research groups which are directly related to the topics studied on the MAOT programme.

More information about the SAOT can be found on the joint web portal: **www.aot.uni-erlangen.de**

The SAOT doctoral programme is funded by the 'Excellence Initiative, of the German Federal and State Governments to Promote Science and Research at German Universities'.

# COMING TO GERMANY

Studying abroad is interesting, exciting and a significant step not only in terms of academic qualifications but also in personal development. It is, however, a major challenge as well. The MAOT team is there to support you with:

- comprehensive information online regarding studying and living in Erlangen and how to come to Germany. The MAOT office helps students to find accommodation in halls of residence or individual apartments. They also support students in the first few days by dealing with local administrative requirements and regulations.
- A range of activities for international students organized by the University and student initiatives to support new students in their first weeks. Language courses and courses about German culture (country, people and history) are offered. These courses and social events provide ideal opportunities to make new friends.
- The MAOT office is an exclusive partner for MAOT students. It offers help with all manner of administrative issues relating to the University or other authorities.

## SCHOLARSHIPS

Financial support from MAOT and SAOT is potentially available. The MAOT office also supports students in applying for external scholarships, for example to the DAAD (German Academic Exchange Service).

## COMING TO GERMANY

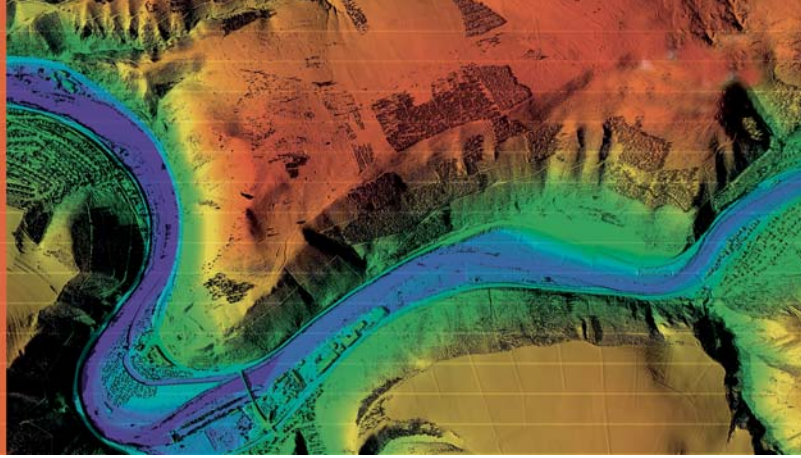
Depending on the country of origin, some administrative effort might be needed for a student to come to Germany. As the situation differs significantly from country to country, we strongly recommend that you ask at the German embassy or consulate in your country for advice as soon as possible.

### The MAOT administrative process is as follows:

1. Application procedure as described on page 8.
2. Acknowledgement by MAOT and the University. Students get an official letter of acceptance.
3. Students arrange travel to Germany in accordance with the regulations applicable for their country. If a visa is required, this should be applied for as early as possible.
4. MAOT supports students in dealing with the authorities within Erlangen/Germany after arrival in Germany.

The MAOT office can be contacted for information on all issues concerning visa and travel and can offer support in dealing with the German authorities. Please note, however, that legal regulations limit the help we can provide with these matters.

# OPTICAL METROLOGY



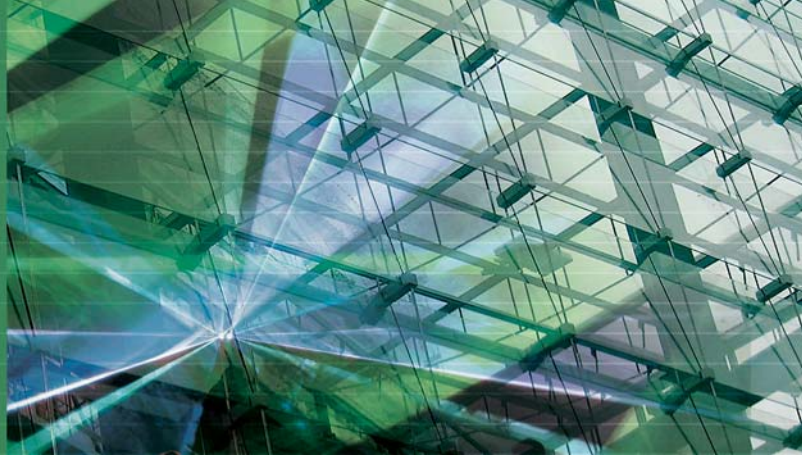
**Light is an excellent tool for gaining remote information without any contact with the object.**

Optical Metrology is of increasing importance in all areas of our daily life, from the exchange and trade of goods through to all aspects of product development and production. Applications are found in medicine, environmental detection, process engineering, and the experimental determination of data in all natural science disciplines and many other areas. Optical measuring technologies represent the only method of acquiring objective quantitative information about technical and physical quantities because of the contactless active principle. The rapid spread in the use of optical measuring techniques in science and technology is also a consequence of the high level of accuracy in measuring and a high spatial and temporal resolution. These technologies are used to determine fundamental values in basic physical research, in the chemical industry for process controlling, during traffic supervision to safeguard airspace, in medicine for purposes of diagnosis and during product development.

During training and research, students will gain extensive knowledge in the following ares: optical methods for the determination of physical values, ultra-precise measurements of optical quantities, laser techniques for process diagnostics and thermophysical properties determination, sensors, measurement principles and methods for different physical and chemical applications, application of optical high precision measurement procedures for geometrical quantities of workpieces, machine tools and assembly equipment, optical methods in medicine for diagnostics and monitoring and optical methods for environmental pollution analysis and environmental protection.

Optical methods are applied in a new determination of physical units, for example, a new standard of time based on an atomic clock using optical frequencies which has an accuracy rate 1000 times better than conventional standards that use radio frequencies. Traceable methods for the calibration of optical measurement systems will also be the focus of research and training. Optical frequency measurements will improve knowledge of fundamental constants, such as the Rydberg constant and the fine-structure constant. Ultra-precise atomic spectroscopy can enable the testing of fundamental physical theories, for instance, relativity, quantum electrodynamics and CPT invariance.

# OPTICAL MATERIAL PROCESSING



**Light as a tool has revolutionized industrial manufacturing. Within the last decade the laser in particular has changed automotive construction, micro- and nanotechnology.**

Now a standard tool, the laser has replaced almost all traditional manufacturing methods, such as like spot welding. The rapid progress seen in computer technology has only been possible due to modern optical technologies.

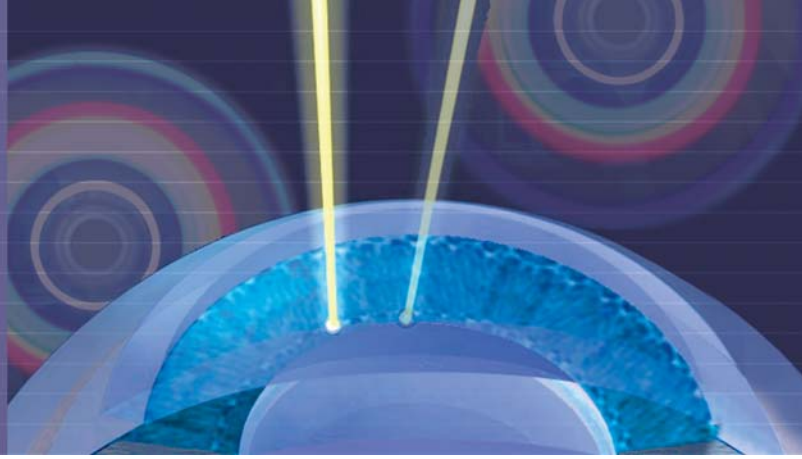
The 'Optical Material Processing' topic will provide in depth knowledge of laser-material interaction and the system technology involved. This is crucial to the realization of future developments in the field of optical material processing, which pushes the boundaries of the physically possible. The goal is to make the connections between the physical fundamentals of beam propagation and interaction of light wave and material, the relevant material science aspects and also implications for manufacturing technology in system technology and applications. The increasing demands for machining quality, for example, make greater the need for improved process monitoring and control.

Whilst lectures cover the basics of laser-material interaction, there will also be a practical seminar in which groups of students directly investigate an application of laser manufacturing technology, such as laser cutting or welding in the machine shop.

Lectures in this topic area also cover important aspects of system technology including beam generation, laser types, beam guidance, laser safety and the clamping of the work piece. An insight into the world of nanotechnology is also given. In additon to experiments, simulation plays an important role in acquiring in depth knowledge of processes and process layout. Since simulation is now essentially a prerequisite of many processes, such as, for example, lithographic manufacturing methods using electronic nanostructures, this subject will be given particular attention. The students will acquire a range of skills to enable them to become competent partners for industry and to be a part of solutions for current scientific challenges, such as the welding of zinc-coated steel sheets or sub-wavelength structuring using ultra-short pulsed lasers.

We work in close cooperation with the Bavarian Laser Centre (BLZ), situated just 100 meters away from the MAOT building to provide students with extensive practical experience. This link between fundamental research and industrial application illustrates the particular value of the MAOT, not only as an academic education but also as a qualification for a successful career in science.

# OPTICS IN MEDICINE



**Laser and optical technology in general play a crucial role in diagnostics and therapy in modern medicine. In order to understand the interaction between light and biological tissue it is necessary to have a fundamental understanding of both.**

The Optics in Medicine topic will look from a macroscopic perspective at the structure of the human organism and its organ parts down to the level of tissue and cells. The eye is ideal subject to study in this respect as here remarkably different types of tissue are functionally linked in a very confined space. The eye itself is a biological optical system that converts light into chemical signals and then, finally, electrical signals. It is also extraordinary well suited for optical diagnostics and therapy because light can pass through the cornea and the lens deep into the eye.

An accompanying seminar will give students the opportunity to use x-ray/CT/MR images, perform microscopy exercises and develop skills in modern imaging systems, such as electron microscopes, laser scanning microscopes and fluorescence microscopes. Another focus will be on the use of optics in diagnostics. The functional structure, changes and illnesses of the eye will be discussed in connection with modern optical diagnostics.

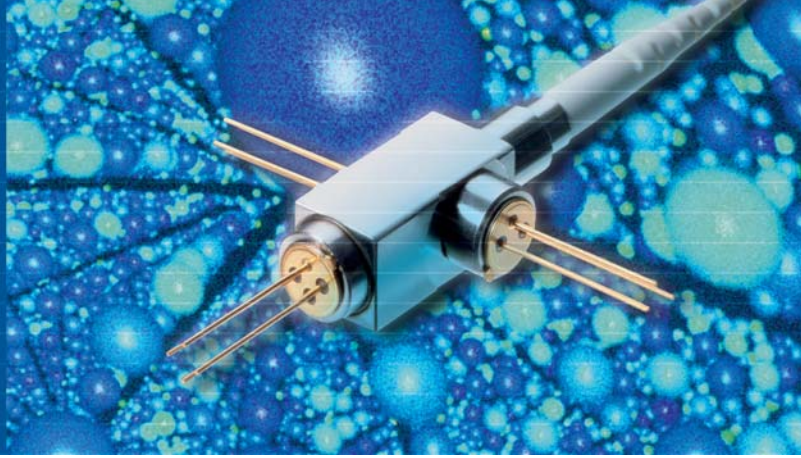
Aside from the eye there are other interesting points of contact between the fields of medicine and optical technologies. Fluorescence spectroscopy, for instance, can be used as a non-invasive diagnostic tool to detect cancer of the stomach.

Lectures will discuss in detail the possibilities and limits of the use of lasers in therapy so as to enable students to work on the specifications of lasers used for therapy in the future.

MAOT students will have the opportunity to learn the basics of several laser systems used for therapy and to perform practical experiments in a seminar.

Erlangen is an excellent place to study this topic. The region is not only a centre of excellence in optical technologies and photonics, but also the 'Medical Valley' of Germany. The internationally renowned University Hospital is located at the heart of the city and provides extensive modern buildings and infrastructure. Siemens Medical Solutions, a global player in medical engineering is also based in Erlangen. The city represents an exciting and motivating environment in which to study and research at the interface of medicine and technology.

# OPTICS IN COMMUNICATION



**Optical communication system technology is one of the most rapidly evolving scientific fields driven by ever increasing demands for higher data transport capacity and longer transmission length.**

There are many exciting challenges for the development of the next generation of optical networks. The topic 'Optics in Communication' provides the knowledge required to face these challenges.

The classes cover a broad range of subjects from the fields of fiber optics and optoelectronic devices, as well as optical communication system design. Firstly linear and nonlinear effects in optical fiber and their respective impact on signal propagation are discussed in detail. The principles of different devices, subsystems and various transmission concepts also are covered. This knowledge is then extended further through a discussion of the advanced complex optical communication systems that form the backbone of today's modern information society. In addition to physics-related aspects, knowledge about concepts, management and the operation of such networks is given particular attention. Students will be given an in depth understanding of current research and development projects in this area.

Future technologies from the field of quantum optics, such as quantum information technology, quantum communication and encryption are dealt with in this topic area. Fundamentals and the quantum physics view of components are explained and discussed with a focus on experimental realization.

Optics in Communication and IT brings together various disciplines. Developing innovative transmission formats and al range of optical solutions for signal processing and regeneration requires a sound understanding of the underlying physical effects, as well as skills in signal processing and information technology. Additionally, computer simulations of optical components, links and networks are essential considering the scale and complexity of today's and, even more so, of tomorrow's communication networks.

The days of transmitting the occasional e-mail via optical networks are long gone. Triple Play, voice-over IP communication and digital broadcasting now drive the development of modern communication systems. New services such as media-on-demand and video communication will become more and more common in everyone's life. To maintain innovation, highly qualified scientists and engineers are needed to help pave the way for a new multimedia age.

# OPTICAL MATERIALS AND SYSTEMS

**New optical materials and efficient light sources form the basis of optical systems design. Tailor-made optical materials and elements using engineered optical functionality benefit from technological progress in micro- and nano-structuring.**

In 'Optical Materials and Systems', students are introduced to commonly used light sources, such as different types of lasers and light-emitting diodes, based on both semiconductors and organic compounds. The wavelength range considered extends from the optical spectrum to the THz regime. Interest in this field of the electromagnetic spectrum has grown considerably in the past few years and there are potential applications in biomedical sensing and imaging or in THz astronomy.

Micro- and nano-structured optical materials have recently been given considerable attention as the ability to produce high quality structures of the order of or smaller than a light wavelength opens up new opportunities to determine the optical properties of materials. Lithography is the main tool employed to fabricate structures on a flat surface, using laser light for wavelength structures and an electron beam for much smaller structures.

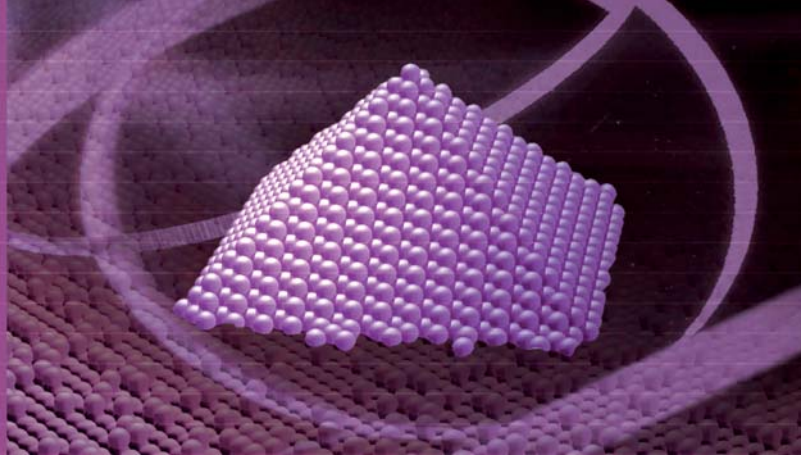
Other two-dimensional structures are photonic crystal fibres (PCF), that is fibres with holes stretching along the entire length of the fibre, showing a regular pattern of holes at the cross-section. These two-dimensional photonic crystals allow the study of light-matter interactions in a confined space and with a very long interaction length.

There are a wide variety of applications of PCF, for example, in telecommunications, metrology, chemical and biological sensing and gas-lasers. The Institute of Optics, Information and Photonics, a Max Planck Research Group, in Erlangen has all the necessary facilities to produce micro- and nano-structured materials both by lithographic methods and by drawing PCF. Joint cooperation projects give students the opportunity to gain practical experience of these techniques.

Microoptical elements, such as micro lenses and diffractive optical elements are advanced design elements in optical systems, their main applications being in beam shaping, interferometry or wave front sensing. Such elements can be created using the laser lithography system in place. As the design of such elements often requires simulation techniques, there is a close link to the computational optics module.

A prominent property of light, which is nevertheless often neglected in optical systems design, is polarisation. In high numerical aperture optics, however, the choice of polarisation is essential in optimizing system properties. Unusual polarisation states, such as radial or azimuthal polarisation have turned out to be particularly interesting in this respect.

# COMPUTATIONAL OPTICS



**Numerical simulations and computer-based techniques are essential tools in optical technologies.**

The vast field of applications includes image-based modeling and rendering, multi-dimensional data visualization and computer vision, as well as simulation and optimization of optical systems, lasers or optical fields in nanostructures. The power of today's computer systems is increasing dramatically which allows us to solve tasks that only few years ago seemed impracticable. The Computational Optics topic provides the basic knowledge necessary for the generation and implementation of such computer-based methods and simulations.

In the classes the key topics of generation, propagation and manipulation of optical waves and the relevant mathematical descriptions are studied with respect to simulation. A discussion of methods of numerical simulation and modeling, such as finite-element or finite-difference time-domain approaches and a look at software engineering provides students with a comprehensive understanding of the subject. The knowledge gained in the module not only allows the effective use of existing software tools, but also enables the students to develop new simulation tools that allow the simulation of complex optical systems.

The lectures on 'Computational Optics' primarily deal with key methods of simulation in optics and the fundamentals of the physics of lasers together with their relevant mathematical models. In this context, the numerical simulation of laser systems and concepts for the development and implementation of numerical algorithms in optics are studied.

A further subject of focus is the visualization of comprehensive data sets. Students become familiar with techniques used to visualize and interpret large amounts of data with an emphasis on real-time processing.

Medical tomography scans acquire vast amounts of multi-dimensional data. Only the visualization of these complex data fields with the help of high-power computers and sophisticated coding and sampling techniques makes tomography the valuable tool it is in modern medicine. Real-time processing opens up the way, not only to medical diagnosis but also to computer-assisted surgery, the design of individually tailored implants or new techniques, such as virtual endoscopy.

# LIVING IN ERLANGEN


## CITY

Erlangen is a charming, modern city, located in the thriving 'Greater Nuremberg' region at the heart of Europe.

The city of over 100,000 inhabitants has a pleasant old town, very good traffic infrastructure and good shopping facilities, an excellent health care system and, in addition to the second biggest university in Bavaria, a well-established industrial base. Siemens has its second biggest location worldwide in Erlangen and the city is also home to many companies highly specialised in medical engineering (Erlangen is a 'medical valley'). Other leading world brands, such as Adidas or Puma have their headquarters nearby.

## REGION

Nuremberg has a population of over 500,000 and is just 15 minutes away by train; Munich is less than two hours. The world culture heritage cities of Bamberg and Regensburg are also just a short distance from Erlangen.

Nuremberg is an important transport hub at the centre of an extensive railway network; most major German cities, such as Berlin or Hamburg and many other European countries, can be reached within four to five hours. Nuremberg airport – located between Erlangen and Nuremberg – offers convenient connections worldwide.

'Frankonian Switzerland' to the north of Erlangen offers gentle meadows as well as rocky cliff faces ideal for free-climbing, mountains for hang-gliding, rivers for rafting and exciting caves to be explored.

## PEOPLE

With 20,000 students and 10,000 employees at the University of Erlangen-Nürnberg and 20,000 people working for Siemens in offices and research centres, Erlangen is a city of highly qualified and highly skilled people who come here from all over Germany and, indeed, from all over the world. People are generally understanding and welcoming. Some people may not talk much, but they are friendly. Living is easy here.

Combining green parks, traditional architecture and modern industrial buildings with direct motorway access and one of the best networks of bicycle lanes in Germany, this is Erlangen.

In spring and fall apple and cherry trees create a colourful landscape; in summer the numerous beer gardens open up. In winter you can taste the delights of mulled wine (“Glühwein”) and gingerbread (“Lebkuchen”) at the famous Christmas markets in Nuremberg and almost every Bavarian city. In Erlangen you can really enjoy life, as well as your studies.