



annual report
2009 / 2010

INSTITUT FÜR
TECHNISCHE OPTIK
UNIVERSITÄT STUTTGART



Universität Stuttgart

INSTITUT FÜR TECHNISCHE OPTIK
UNIVERSITÄT STUTTGART

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ANNUAL REPORT 2009/2010



Dear Reader,

another two years filled with many activities in different fields and enriched with fruitful national and world wide cooperation have passed since the ITO staff reported in 2009 about their research activities in a comprehensive report. Thus it is again time to inform our partners, sponsors and customers about our recent advances in the field of Applied Optics.

The basic understanding that determines our work remains unchanged: striving for excellence in research and teaching, together with a good balance of continuity and systematic renewing. Modernization of our environment and equipment is still an ongoing process. Our reactive ion etching facility is meanwhile successfully working, although strict environmental requirements delayed the complete start of operation by about 2 years. The installation of the Helios Nanolab 600 focused ion beam (FIB) tool is also on a good way even though the operation of such a high-end facility in a clean room environment imposes some special boundary conditions. Both tools widen our possibilities in the field of nanotechnology considerably and we are optimistic that our planned activities in diffractive optics and high resolution imaging can be realized in the near future. But we have learned, partly very painful, that the step across 3 orders of magnitude from the micro to the real nano world has to be paid by an increased effort of the same magnitude and beyond. Our aim to assure flexible structuring technologies with high resolution and reliability not only for a few crucial experiments but for making dedicated optical components is unbroken.

To make sure that ITO will be able to fulfil its commitment also with changing boundary conditions we have installed a powerful alliance with competent partners in photonics beyond the framework of our faculty: the Stuttgart Research Center of Photonic Engineering¹. Here experts from 3 different faculties – physics, electrical engineering and mechanical engineering – are working together on topics where the expertise of one faculty is insufficient to meet the grown challenges. Some very first joint results could be already presented: our new but meanwhile approved concepts in resolution enhancement beyond the diffraction limit by a dedicated design

of negative index materials and the fabrication of a new class of flexible illumination devices with spatially varying polarisation state. Further projects have been already started and the application for a collaborative research centre under the umbrella of the German Research Association DFG in the scope of future photonic circuits is on the way. Such interdisciplinary cooperation in larger scientific networks, assembled to meet ambitious mid- and long-term targets, is gaining more and more in importance.

As a member of the Faculty of Mechanical Engineering, the Institute represents the University of Stuttgart in the field of Engineering Optics in research and education. Together with our national and international partners, our research work focuses on the exploration of new measurement and design principles and their implementation in new optical components, sensors and sensor systems. One of our central goals is the extension of existing limits by combining modelling, simulation and experimental data acquisition in the context of actively driven measurement processes. Several ambitious objectives are on our agenda such as the implementation of a multi-sensor measurement systems where the systematic cooperation of different classes of sensors is controlled by a sophisticated assistance system, the implementation of the prototype of our new tilted wavefront interferometer with the objective to realize a much more effective approach for the testing of aspheres and free-form surfaces, and the further improvement of our model-based reconstruction procedures for the inspection of sub-wavelength structures.

Our overall research approach "Optical Metrology and Systems Design" is structured into eight main research directions:

- Active Metrology
- Model-based Metrology,
- Remote Metrology,
- Resolution Enhancement,
- Computational Imaging,
- Sensor Fusion,
- Hybride Optics and Systems, and
- Sensor Integration.

Together with strong interactions between these groups, this gives the Institute a strength in depth over a broad range of optics activities. The considerable number of research projects that are referred to in this report reflects again the success of this approach.

As already mentioned, high-quality teaching for our students on different levels (bachelor, master, phd) is – besides our wide research activities – an ongoing strong commitment of ITO. Thus we have started in 2010 the new consecutive bachelor-master course in medical technology – a joint and challenging project of the University of Stuttgart and the Eberhard Karls Universität Tübingen. Both universities complement each other with their strong commitment in engineering and medicine, respectively, in an ideal way. The response of the students was very motivating and ITO is one of the drivers of that course. In 2011 we will start a new master course with the dedication "Micro-, Precision- and Photonics Engineering".

To cope with our ambitious and extensive approach to Applied Optics, a deep understanding of physics needs to be combined with practical engineering implementation. This is a daily challenge for all members of the staff. However, a good mixture of graduates in physics and engineering, a vital and innovative scientific climate, that considers the interdisciplinary cooperation with numerous national and international institutes, and a continuous observation of the technological and scientific progress are a good basis to meet these and future challenges.



Wolfgang Osten

¹ <http://www.scope.uni-stuttgart.de/>

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Team and structure



Teaching

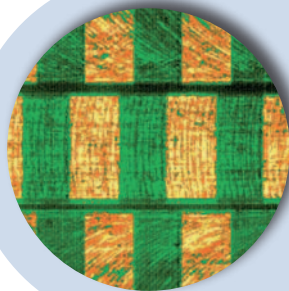
E. Steinbeißer

Chair

Prof.Dr. W. Osten

Deputy

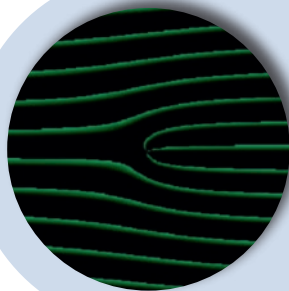
Dr. T. Haist



3D-Surface Metrology

W. Lyda

- Macro and Micro Metrology
- White Light Interferometry
- Spectral Interferometry
- Confocal Microscopy
- Fringe Projection
- Sensorfusion and Measurement Strategies



Active Optical Systems and Computational Imaging

Dr. T. Haist

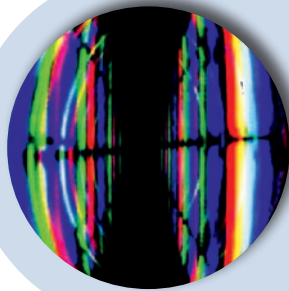
- Active Wavefront Modulation and Sensors
- Adaptive Optics
- Dynamic Holography
- Optical Tweezers
- Components, Algorithms and Strategies
- Waveoptical Computing
- Computational Imaging



High Resolution Metrology and Simulation

Dr. K. Frenner

- Modelling and Rigorous Simulation
- Computational Electromagnetics
- Inverse Problems
- High Resolution Microscopy
- Scatterometry
- Optical Metamaterials



Interferometry and Diffractive Optics

C. Pruß

- Testing of Aspheres and Freeform Surfaces
- Design, Fabrication and Testing of Hybrid Refractive/Diffractive Systems
- Microoptical Systems
- Tailored Optics for Metrology Applications
- Interferometry and Wavefront Sensors



Coherent Metrology

Dr. G. Pedrini

- Digital Holography
- Shape and Deformation Measurement
- Dynam. Holography and Microscopy
- Non-destructive Testing
- Phase Retrieval
- Remote and Virtual Laboratories

Administration, Software Engineering & Technical Support

Staff of the Institute

Status quo: June 2011

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Guest Scientists

Prof. Dr. Bahram Javidi** Univ. of Connecticut (USA)
Dr. QuanYing Wu Soochow Univ., Suzhou (China) 9/2009 – 6/2010
Dr. Guohai Situ* Chin. Academic of Sciences, Beijing (China) .. 3/2008 – 9/2010
Yizhuo Zhang Beijing Univ. of Technology (China) 9/2009 – 9/2010
Jun Ma Nanjing Univ. (China) 9/2009 – 12/2010
Giorgio Pariani Politecnico di Milano (Italy) 10/2010 – 3/2011
Dr. Caojin Yuan* Hunan Univ. (China) 12/2009 – 6/2011
Prof. Ventseslav Sainov Bulg. Academy of Sciences (Bulgaria) 11/2010 – 12/2010

* Humboldt fellowship

** Humboldt prize-winner and stays at the ITO for altogether one year

Foreign Guests visiting the Institute: 2009 – 2010

Prof. Dr. Yoshiharu Morimoto	Wakayama Univ. University, Japan	January 2009
Prof. Dr. Motoharu Fujigaki	Wakayama Univ. University, Japan	January 2009
Dr. Florian Bociort	Univ. Delft, Netherlands	February 2009
Prof. Dr. Charles Joenathan	Rose-Hulman-Univ., USA	March 2009
Dr. Marc Georges	Univ. Liege, Belgium	September 2009
Prof. Dr. Pryputniewicz	Worcester Polytechnic Institute, USA	September 2009
Prof. Dr. Charles Vest	President National Academy of Engineering, USA	September 2009
Prof. Dr. Ichirou Yamaguchi	Gunma Univ., Japan	September 2009
Prof. Dr. R. Dändliker	University of Neuchatel, Suisse	September 2009
Dr. Chris Koliopoulos	Zygo, USA	September 2009
Dr. Jan Burke	CSIRO, Australia	September 2009
Prof. Xiang Peng	Shenzhen Univ., China	September 2009
Prof. Dr. Armando Albertazzi Jr.	Univ. Florianopolis, Brazil	September 2009
Dr. Arie den Boef	ASML, Netherlands	September 2009
Dr. Kay Gastinger	SINTEF, Norway	May 2010
Prof. Dr. Kazuyoshi Itoh	Osaka Univ., Japan	June 2010
Dr. Nadya Reingand	CeLight Inc., Silver Spring, USA	June 2010
Dr. Arie den Boef	ASML, Netherlands	June 2010
Prof. Ventseslav Sainov	Bulg. Academy of Sciences, Bulgaria	September 2010
Prof. Yoris Dirckx	Univ. Antwerp, Belgium	September 2010
Dr. Yu Fu	National Univ. Singapore, Singapore	October 2010
Prof. Dr. Kazuyoshi	Itoh, Osaka Univ., Japan	November 2010

New professorship for optical design and simulation

Beginning of February 2011 Prof. Dr. Alois Herkommer occupied the newly established professorship for „optical design and simulation“ at the ITO. The position could be instituted due to the introduction of the joint bachelor program “medical engineering” at the universities of Stuttgart and Tübingen and is partly funded by the German optical industry. Participating companies are: Trumpf GmbH & Co. KG, Polytec GmbH, Karl Storz GmbH & Co. KG, Sick AG, Berliner Glas KGaA Herbert Kubatz GmbH & Co and Leica Microsystems GmbH.



Alois Herkommer
new professor for optical design
and simulation at the ITO

Alois Herkommer was born in 1967 in Thannhausen (Germany) and studied physics at the University of Ulm. After his diploma he was engaged at the department of quantum physics at the University of Ulm under Prof. Dr. Wolfgang Schleich. His research was focused on the interaction of atoms with light fields and he finished his doctor-thesis in 1995 with the title „Atom optics in quantized light fields“. In 1996 he decided for a career in industry and joined the Carl Zeiss AG in Oberkochen. Until 2011 he filled several positions within the company: From 1996 to 2000 he worked as an optical designer and project manager on the development of high performance optical systems for lithographic projection and wafer inspection systems. From 2000 to 2005 he was team leader and senior scientist of the optical design group of the Carl Zeiss Laser Optics GmbH. The work of the group was focused on the development of optical components for Excimer lasers, spectral components, laser material processing systems and X-ray optics. Since 2005 he was heading the optical design group at Carl Zeiss SMT GmbH, which is responsible for

the optical design of illumination and projection optical systems for microlithography.

Since February 2011 Prof. Herkommer is with the ITO – now looking forward to merge his broad background in optical design with the optical competencies at the ITO. His goal is to generally extend expertise for the optical design of imaging and illumination optical systems at the University of Stuttgart. Accordingly he will focus on the development of design and simulation methods, with a special focus on the application and integration of complex surfaces, like diffractive and microoptical structures. One research topic is the combination of ray-tracing methods with waveoptical and rigorous simulations.

Moreover Prof. Herkommer is interested in the design and application of optical systems for medical purposes: Optical systems are the basis of many modern medical devices. In consequence innovative optical designs are an important factor in the development of more efficient systems for diagnostics as well as for therapy. Advanced and competitive medical devices will be beneficial for patients as well as for economy, since the medical industry is an important business factor in Germany. In order to fulfill industries growing demand on graduates in the field of medical engineering, the universities of Stuttgart and Tübingen have recently established the new joint bachelor program “medical engineering“. One fundamental part of the curriculum is an education in optics. Courses in technical optics, optical design and optical metrology within this bachelor program and also within a consecutive master program will thus represent the focus of Prof. Herkommers teaching activities.

I am proud to be selected for this challenging position. Being part of such an excellent optical institute as the ITO is a great honor for me and I am looking forward to work with the team on innovative optical designs for many applications. Thank you ITO for the very warm welcome!

Alois Herkommer

For more information on medical engineering: www.uni-medtec.de

Project partners

Project collaboration with the following companies and organisations

(and many others):

ASML Netherlands B.V.	Veldhoven, Netherlands
Audi AG	Ingolstadt
Carl Zeiss AG	Oberkochen
Carl Zeiss SMT AG	Oberkochen
Continental Teeves AG	Hannover
Daimler AG	Untertürkheim
FOS Messtechnik GmbH	Schacht-Audorf
Fraunhofer IPA	Stuttgart
Fraunhofer IPT	Aachen
Fraunhofer IWU	Chemnitz
GSAME, University Stuttgart	Stuttgart
Holoeye AG	Berlin
HSG-IMAT	Stuttgart
Ifm electronic	Meckenbeuren
IMTEK, University Freiburg	Freiburg
Institute of Industrial Manufacturing and Management, University Stuttgart	Stuttgart
Institute of System Dynamics, University Stuttgart	Stuttgart
Instrument Systems	München
LaVision GmbH	Göttingen
Mahr OKM GmbH	Jena
MAN Truck & Bus AG	Nürnberg
PMD Technologies GmbH	Siegen
Polytec GmbH	Waldbronn
Promicon	Kirchheim / Neckar
Robert Bosch GmbH	Gerlingen
Singulus Mastering BV	Eindhoven, Netherlands
U-L-M Photonics	Ulm
University of Wuppertal, Prof. Tibken	Wuppertal
Volkswagen AG	Wolfsburg

Studying optics

Our curriculum is primarily directed towards the students in upper-level courses of **Mechanical Engineering, Cybernetic Engineering, Mechatronics, and Technology Management**. Since the academic year 2009/10 we offer for the first time our courses "Fundamentals of Engineering Optics" and "Optical Measurement" for the bachelor students in the above mentioned degree programmes.

For the next academic year 2011/12 we especially recommend the new master programme "Micro-, Precision- and Photonics Engineering". We also welcome students from other courses, such as "Physics" and "Electrical Engineering" and "Information Technology".

Concerning the main subject "Engineering Optics" we offer the following:

Core subjects:

■ Fundamentals of Engineering Optics

(Prof. Dr. W. Osten)

basic laws and components: optical imaging with lenses, mirrors, and prism; basic optical set ups; optical systems and devices (the human eye, magnifying glass, microscope, and telescope); physical optics, physical limits of optical images, resolution of optical devices; geometrical and chromatic aberrations and their influence on picture quality, basic laws of photometry.

■ Optical Measurement Techniques and Procedures (Prof. Dr. W. Osten / Dr. Körner)

basics in geometrical optics and physical optics; holography; speckle; components and systems: light sources, lenses, mirrors, prism, stops, light modulators, the human eye and other detectors; measuring errors; measuring techniques based on geometrical optics: measuring microscopes and telescopes, structured illumination, application of moiré-phenomenon; measuring techniques based on physical optics: interferometrical measurement techniques, holographic interferometry, speckle measurement techniques.

■ Optical Information Processing

(Prof. Dr. W. Osten)

fourier theory of optical imaging; basics of the wave theory, coherence, frequency analysis of optical systems, holography and speckle, spectrum-analysis and optical filtering; digital image processing: basics as far as methods and applications.

Elective subjects:

- Optical Phenomena in Nature and Everyday Life (Dr. T. Haist)
- Fundamentals of Colorimetry and Digital Photography (Dr. K. Lenhardt)
- Polarization Optics and Nanostructured Films (Dr. K. Frenner)
- Introduction to Optical Design (Dr. Ch. Menke; Zeiss)

Additional studies:

- project work and thesis within our fields of research
- practical course "Optic-Laboratory"
 - speckle measurement
 - digital image processing
 - computer aided design of optical systems
 - measurement of the spectral power distribution
- practical course "Optical Measurement Techniques"
 - 3D surface measurement applying fringe projection
 - digital holography
 - 2D-interferometry and measurement
 - quality inspection of photo-objectives with the MTF measuring system
- common lab for mechanical engineering (APMB)

The research groups



3D-Surface Metrology

The objective of the group is the analysis and the implementation of new principles for the acquisition of optical 3D-surface data of engineering and biological objects over a wide scale. Our main focus is on the enhancement of the metering capacity by a combination of physical models and optimized system design.

Current research activities are:

- 3D-measurement applying fringe projection and deflectometry (macro- and microscopic)
- adaptive techniques using spatial light modulators
- confocal microscopy
- white light interferometry
- spectral interferometry
- sensorfusion and data interpretation strategies

Contact: ofm@ito.uni-stuttgart.de



Active Optical Systems and Computational Imaging

The objective of our work is the development of flexible optical systems in order to enable new applications, especially within the field of scientific and industrial metrology. To achieve this goal, we make use of different modern light modulation technologies and computer-based methods. One focus of our work lies in the application of holographic methods based on liquid crystal displays and micromechanical systems for various applications ranging from optical tweezers to aberration control and testing of aspherical surfaces.

Main research areas:

- active wavefront modulation and sensors
- adaptive optics
- active wavefront sensors
- dynamic holography
- components, algorithms, and strategies
- waveoptical computing
- computational imaging

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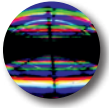
High Resolution Metrology and Simulation

The goal of this research group is the investigation of the interaction of light with 3d object structures in the micro and nano domain. Along with experimental research, one major aspect is the rigorous modelling and simulation as an integral part of the active metrology process. The analysis of all information channels of the electromagnetic field (intensity, phase, polarisation state of light) allows us to obtain sub-wavelength information about the structure.

Current research areas:

- modelling and rigorous simulation
- computational electromagnetics
- inverse problems
- high resolution microscopy
- scatterometry
- optical metamaterials

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Interferometry and Diffractive Optics

The goal of our research activity is to explore new measurement concepts using diffractive optics. One important application is the testing of optical surfaces, in particular, aspheric lenses. For this purpose we design and produce computer generated holograms (CGH). At the same time, we develop flexible measurement techniques for aspheres and freeform surfaces that aim to replace static null correctors. In addition to CGH for interferometry, our in house production facilities allow us to produce diffractive elements and micro-optics for a wide variety of applications such as imaging systems, UV-measurement systems, beam shaping applications and wavefront sensing.

Our research areas include:

- testing of aspheric and freeform surfaces
- design, fabrication and testing of hybrid refractive/diffractive systems
- interferometry and wavefront sensors
- tailored optics for metrology applications
- fabrication of diffractive optics

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Coherent Metrology

Our research objective is the analysis and application of methods based on coherent optics for the measurement of 3D-shape and deformation and to determine the material properties of technical objects and biological tissues. Aside from the quantitative measurements of form and deformation, methods for non destructive material testing are also analysed and applied.

Research areas include:

- digital holography
- pulsed holographic interferometry
- dynamic strain measurements on biological samples
- shape measurement
- wavefront reconstruction
- holographic non-destructive testing
- endoscopy
- remote and virtual laboratories

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