Solutions with light

The Institute is known for its developments of novel optical materials and elements - from basic to application orientated research.

The Institute practices fundamental and applied research in the fields of micro- and nano-optics, fiber and waveguide optics and ultrafast optics. It develops novel optical materials, elements and concepts for information and communication technology, life science and medicine, security and mobility, environment and energy as well as process technology including material processing and optical measurement techniques.

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Departments and Research Groups
The Institute

Staff

budgetarily financed: 4 university professors
2,5 scientific staff
9,4 technical /admin. staff
externally funded: 1 endowed professor
2 junior professor
88,4 scientific staff
6,3 technical /admin. staff

Teaching – Elective courses

- Astrophotonics
- Beugungstheorie elektromagnetischer Wellen
- Computational Photonics
- Experimentelle Methoden der optischen Spektroskopie
- Festkörperanalyse mit Ionenstrahlen
- Fundamentals of modern optics
- Fourier Transformation and Sampling Theory
- Grundlagen der Laserphysik
- Imaging and aberration theory
- Introduction to Nanooptics
- Micro/nanotechnology
- Nanomaterials and their optical applications
- Optical design with Zemax
- Optical Modeling & design I
- Optical Modelling and Design II
- Theoretical nanooptics
- Thin Film Optics
- Ultrafast optics
The Institute

Projects and Budget

External Funds (Revenues 2012):
- German Research Society (DFG) 930 TSD €
- Federal Ministries (BMBF, BMWI) 7,407 TSD €
- Thuringian Ministries (TMBWK, TMWAT) 896 TSD €
- Foundations 97 TSD €
- Industry/Others 912 TSD €
- European Union 166 TSD €

Total: 10,408 TSD €
Cooperations
Fiber & Waveguide Lasers

- Fiber design
- Laser-Simulation Tools
- High-power ultrashort-pulse laser systems
- Few-Cycle Lasers
- Ultrafast Fiber Oscillators
- High-Harmonic Generation
- Fiber-Optic Frequency Conversion
- Microchip lasers

Microscope images (all at the same scale) of a) standard step index fiber with 6 µm core and 125 µm outer diameter, b) 85 µm core rod type photonic crystal fiber with 200 µm air-clad diameter, and c) 108 µm core large-pitch fiber with 340 µm airclad diameter.

Simulated transversally resolved inversion distribution of a saturated fiber amplifier.

Bonded microchip laser on a heat sick.

Highly efficient dielectric diffraction grating employed in a CPA stretcher/compressor unit.

Multimodale, nichtlineare Mikroskopie von Ablagerungen arteriosklerotischer Plaques in einer Humanaorta
Microstructure Technology & Microoptics

- Plasmonic nanostructures
- Resonant reflective monolithic grating structures
- Transmissive reflective and diffractive elements based on effective media
- Metallic and dielectric polarizers from IR to DUV
- 3D nano-structuring of crystals with ion beam enhanced etchings
- Effective media for reflection reduction of smooth and micro-structured surfaces
- Material-scientific aspects

Abb. 3. Beispiele für am Zentrum ultra optics realisierte photonische Nanostrukturen: a) Beugungsgitter mit durch effektive Nanomaterialien realisiertem Gradienverlauf; b) mittels Ionenimplantation strukturierter LiNbO₃ phantonscher Kristall; c) Abbildungselement aus Nanomaterial; d) Metallstrahlen-UV-Polarisor; e) polarisationsrichtungsunabhängiges Metamaterial; f) Kontrollschritt durch ein doppelschichtiges photonisches Nanomaterial.
Nano Optics

- Plasmonics and near-field optics, scanning optical nearfield microscopy (SNOM)
- Nanostructured optical metamaterials
- Nonlinear light-matter interaction at high optical intensities in micro- and nanostructures, nonlinear dynamics
- Optical micro resonator of high quality
- Nonlinear nano marker for maximum-resolution microscopy
- Opto-optical switching processes in integrated optics
- New optical technologies for astronomical instruments
- Application of nanostructures to enhance efficiency of photovoltaic elements

Measurement signals for scanning across the gap of two coupled disks.

Metamaterial hologram operating at two wavelengths simultaneously, where the wavelength range has been mapped onto the visible for the purpose of illustration. b) Fishnet metamaterial consisting of a three-layer (Au, MgO, Au) system. The lateral parameters $W_x, W_y$ are used to tune the optical properties. c) Scanning electron microcopy (SEM) image of a fabricated prototype metamaterial CGH. Each hologram pixel comprises a few metamaterial unit cells.
Optical Engineering

- Non-sequential field tracing
- Electromagnetic modeling of partially coherent light
- Geometrical optics field tracing technology
- Propagation of non-paraxial harmonic fields
- Rigorous and efficient propagation of general fields through plane interfaces
- Propagation of fields between tilted planes
- Design of light-shaping elements

Unified optical modeling by field tracing: Propagation of electromagnetic fields through the complete optical system (including source and detector) by using the combination of rigorous and approximate solutions of Maxwell’s equations in different subdomains of the system.

Mathematical model of dispersion prism and distribution of two fields on output plane

Input five unequal-weighted fields with different wavelengths. (b) Output field set after propagation for a proper distance.
Optical System Design

**Lens Design**
- Design of modern optical systems
- Aberration theory
- Performance evaluation of optical systems
- Metrology of system quality
- Layout of laser beam delivery systems
- Optimization methods in optical design
- Tolerancing of optical systems

**General simulation of optical systems**
- Simulation of diffraction effects
- Microscopic image formation
- Calculation algorithms of wave propagation
- Straylight and scattering in optical systems
- Modelling of illuminations systems
- Partial coherent imaging and beam propagation
- Point spread function engineering and Fourier optics

Beugungseffekte an einer Fresnellinse.
Ultrafast Optics

- Micro-and nanostructuring with ultrashort laser pulses
- 3D volume structuring inside glasses and crystals
- Linear and nonlinear optics in discrete systems
- Fiber Bragg Gratings
- Medical laser applications in ophthalmology
- Ultra-short pulse laser technology
- THz technology

Local welding of glass with ultrashort laser pulses

Prototype of a saw-tooth-like structure for a diamond micro mill, Dimensions: 100μm x 30μm

Bonded glass blanks after the laser welding
Diamond-/carbon-based Optical Systems

- Optical graphene
- Complex fluids
- Super oscillations
- Algorithmical subwavelength microscopy

Elektronenmikroskopaufnahme einer Subwellenlängenprobe (links). Das Beugungslimit (auch Abbe-Limit genannt) ist markiert und entspricht 266 nm (Beleuchtung erfolgte mit Laserlicht mit λ=532 nm). In einem optischen Mikroskop ist die Struktur nur verschwommen sichtbar (Mitte). Die algorithmische Rekonstruktion macht verloren gegangene Details wieder sichtbar und erzeugt eine Auflösung von ca. 20 nm.

Optical graphene
Complex fluids
Super oscillations
Algorithmical subwavelength microscopy
Manufacturing Technologies for Advanced Micro- and Nano-Optics

- New Patterning Technologies
- Treatment of New Materials
- Development of Sample Applications


(Junior) Research Groups

**Multiphoton Microscopy**
- *junior research group -*

- Bottom-up chemical synthesis of oxide core and gold shell nanowires for imaging and lab-on-a-chip applications
- Top-down fabrication of oxide nanowaveguides for nonlinear ultrafast photonic devices

**Funding**
- Carl Zeiss Stiftung, JSMC, Pro Chance

![Figure 1: Bottom-up synthesized KNbO₃ nanowire with gold nanoshell](image)

**Atomic Layer Deposition**
- *Emmy-Noether junior research group -*

- Fabrication of resonant wave-guides with high sensitivity by atomic layer deposition (ALD)
- In-situ analysis of the nucleation in ALD-processes
- Deutsche Forschungsgemeinschaft

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Microstructure+Technology.html
Small Structures with huge Impact

Aim  
- Development of innovative sensors and photodiodes for efficient and cost effective solar cells based on crystalline and polycrystalline silicon

SIS-Solar Cells  
- The SIS concept (Semiconductor - Insulator - Semiconductor) includes a very simple layer structure, which provides a silicon wafer as a substrate (semiconductor). On the substrate there is a thin barrier layer (insulator), which is coated with a transparent conductive oxide (Semiconductor). The currently used TCO (Transparent Conductive Oxide) is indium tin oxide (ITO) and should be replaced by a much less expensive aluminum doped zinc oxide. The advantage of the SIS concept lies in its easy production using industry-proven sputtering.

Black Silicon  
- High reflection losses of silicon (more than 30%) minor the absorption of the incident light power, especially in a part of the solar spectrum with high power densities. Interface reflection can be reduced by manufacturing stochastic surface structures via reactive ion etching and a broad band, angle-independent antirelective coating can be effected. Thus it can be realized over the entire relevant spectral range extremely effective coupling of the incident radiation in the photoactive region.

The Initiative is funded by the Federal Ministry of Education and Research (BMBF) and the Thuringian Ministry of Education, Economics and Culture (TMBWK).
- Clean room
- Electron beam and Laser Lithography
- Dry etching
- Cross beam, scanning electron microscopy
- Photolitography
- Interference optical surface profilometry
- Scanning nearfield optical microscopy
- Nonlinear optical waveguide characterization
- UV-VIS spectrometry
- FTIR spectrometry
- Rigorous optical simulation
- Ultrashort pulse laser technology
- Laser micro-structuring technology
- Field tracing technics
- Helium ion microscopy