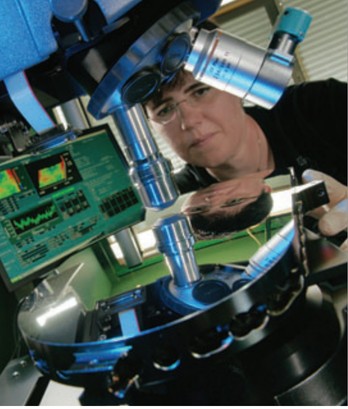
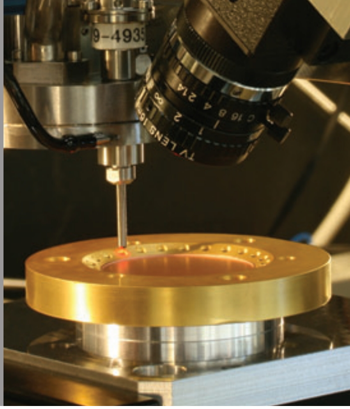
Fraunhofer

IOF

FRAUNHOFER INSTITUTE FOR APPLIED OPTICS AND PRECISION ENGINEERING

SPACE AND ASTRONOMICAL APPLICATIONS





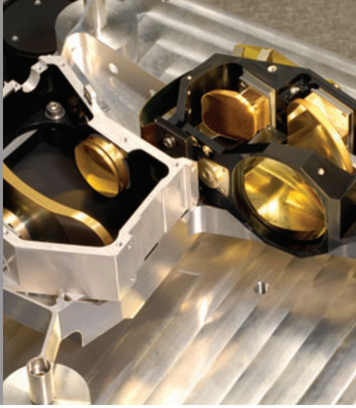
EXPERIENCE IN SPACE INSTRUMENTATION

The Fraunhofer Institute for Applied Optics and Precision Engineering IOF develops innovative optical systems to control light from the generation to the application.

Our claim is to cover the entire photonic process chain from opto-mechanical and opto-electrical system design to the manufacturing of customized solutions and prototypes. In the field of aviation and space, our developments focus on ultra-light weighted and long-term stable optical components and systems. Further key areas are athermal designs, fiber-based laser systems for harsh environments, unique grating solutions, as well as innovative adhesion-free joining and assembling technologies.

The institute is equipped with modern facilities for micro-optic technologies, ultraprecision manufacturing technologies, precision engineering and assembling, state-of-the-art coating machines, methods for surface and optics characterization, and special software for optical and mechanical designs.

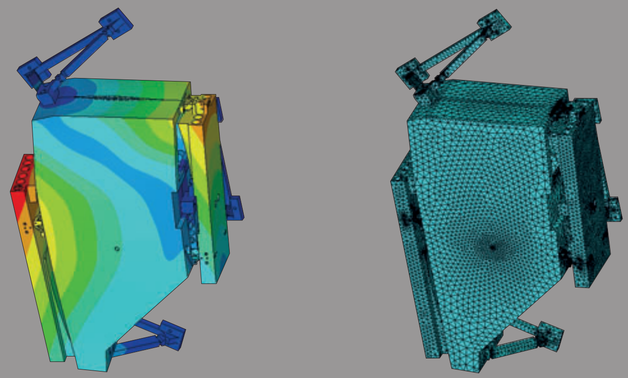
The Fraunhofer IOF belongs to the founding members of the »Allianz Space« and represents a key partner in the development of optical components and systems. Our core competencies will be presented at the following pages.


PROJECTS AND APPLICATIONS

During the last years, the Fraunhofer IOF developed a variety of optical systems in closed cooperation with our customers. The institute was involved in space-borne and ground based space instrumentation projects such as:

- ESTEC project MIO (Micro-optics Technology for Spaceborne Laser Instruments) and its successor MIO-CCN,
- CODAG (Cosmic Dust Aggregation Experiment) – light-weight microscope support allowing adjustment and synchronous motion of two microscopes,
- RapidEye – TMA mechanical design, manufacturing of spherical and aspherical mirrors, and assembly of the TMA telescopes,
- Piston Mirror manufacturing and assembly for the Large Binocular Telescope (LBT),
- Waveguide image-slicer for PEPSI (Potsdam Echell Polarimetric and Spectroscopic Instrument),
- ESA/ESTEC project "Coherent heterodyne scatterometer",
- DLR project METimage – mirror design/fabrication for a rotating TMA telescope,
- EnMAP project – ultraprecise metal mirrors with protected silver and sputtered gold (VIS-NIR-IR) for Environmental Mapping and Analysis Program,
- ESA's GAIA satellite – RVS grating development and flight model fabrication, test CGH for the primary telescope mirror,
- JWST (James Webb Space Telescope) – light-weighted metal mirrors for MIRI (mid infrared instrument), and
- Sentinel 4 – grating design study and demonstrator fabrication for the UV/VIS- and NIR-spectrometer channel.



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DESIGN AND SIMULATION

1 FEM model of the PREMIER telescope; first resonance mode oscillation at 319 Hz.

The Fraunhofer IOF covers the whole design and analysis chain from optical systems design, including special sub-components like gratings, to its mechanical implementation and analyses of the complete optical system. Analysis capabilities comprise stray light analyses as well as structural and thermal FEM simulations, enabling optimization of the system with respect to special requirements imposed on air- and space-borne instrumentation. Simulation and design is carried out using commercial software packages as well as specially developed and adapted tools.

- Optical system design
- Stray light analyses
- Structural & thermal FEM analyses
- Rigorous grating design

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ULTRA-PRECISE MACHINING

The Fraunhofer IOF develops different diamond-based ultra-precision machining techniques suitable for fabricating large and complex shaped optical components like mirrors and mirror systems, lenses and gratings. Different process chains have been established to realize high end metal optics. For shorter wavelength applications and optical components with high demands on shape accuracy and roughness, Magnetorheological Finishing (MRF) is used to improve diamond machined optics.

2 MRF machining of an off-axis asphere.

- Ultra-precision machining based on diamond turning with Slow Tool Servo and Fast Tool Servo extension up to Ø 1000 mm
- Diamond milling and ruling techniques
- MRF figuring of mirrors and lenses with apertures up to 1000 mm
- Patented light-weighting structures and athermal material blends
- Lens centering technology for high-quality optics

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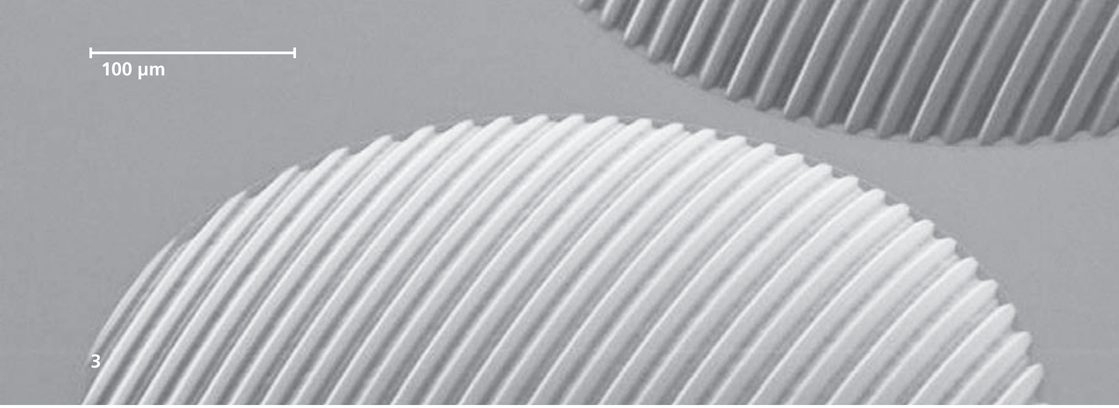

MICRO- AND NANO-STRUCTURED ELEMENTS

3 Lens grating.

Micro- and nano structured elements such as high-resolution gratings are essential components in spectroscopic instruments of different earth-observation and scientific space missions. Also the testing of aspheric telescope mirrors is based on high-precision Computer Generated Holograms (CGH) realized by lithographic micro-structuring. The Fraunhofer IOF operates extensive technological facilities ranging from high-resolution electron-beam- and laser-lithography to mechanical ultra-precision manufacturing for the realization of such elements. These technologies have been proven to fulfill the highest demands on optical parameters like diffraction efficiency, wave-front quality, and stray-light performance.

- High performance spectroscopic gratings
- Advanced fabrication-optimized grating design
- Computer Generated Holograms for asphere testing
- CGH-based alignment features for UP machined aspheric mirrors
- Free-standing spectrometer slits

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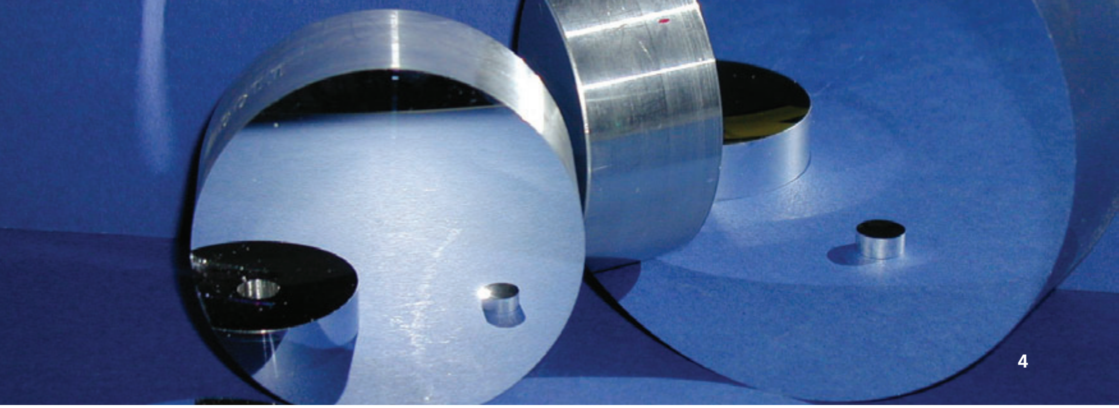

MATERIALS FOR SPACE AND ASTRONOMY

The manufacturing of ultra-precise optical systems requires a profound understanding of the materials applied. Dimensional stable aluminum substrates (Al6061, AlSi40) are coated with an amorphous layer (a-Si: < 10 µm, electroless NiP: < 150 µm) to fulfill the requirements of IR- to EUV – substrates. CTE matching materials like AlSi40 and electroless NiP with a tailored P-content minimize the bimetallic bending for ultraprecise cryogenic optics. Ultra-light weighted aluminum mirrors made by selective laser melting are aiming at next generation space optics.

4 Aluminum mirrors.

- Materials for cryogenic optics with minimized bimetallic bending
- Technical layers (a-Si, electroless NiP) enabling polishing techniques
- Selective laser melting for ultra-light weighted mirrors
- Analysis of dimensional stability of materials via dilatometry and (cryo-) interferometry

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OPTICAL COATINGS AND SURFACE FUNCTIONALIZATION

5 Coated mirror for astronomical application.

The Fraunhofer IOF develops and customizes coatings for astronomical and space applications. The portfolio includes Mo/Si-, Sc/Si- or B_4C-based EUV coatings, Al and fluoride based DUV coatings, Ag-based and Au-based high-reflective coatings, dielectric antireflection coatings, absorbing coatings, and structured coatings. The institute offers performance of coating qualification programs, handling of delicate substrates, cleaning of substrates, construction of holders, and coating of complex optical components.

- High-reflective coatings from EUV to IR (Al-, Ag- or Au-based)
- Antireflection coatings for broad bandwidth and large ranges of incidence angles
- Optical dense structured coatings or absorbing coatings
- Handling and coating of complex optical components
- Realization of test programs for coating qualification

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PACKAGING TECHNOLOGIES

Joining technologies that are designed for harsh environments in space can realize long term stability in the sub-micron and arcsecond range. In addition to classical clamping and adhesive bonding, Fraunhofer IOF offers a versatility of bonding technologies that are suitable for fixation of components made of glass, metal, and ceramics. The focus of the institute is on high mechanical strength, low introduced stress, highest optical transparency, and semi-monolithic, athermal arrangements.

6 Low-stress soldered lens in mount.

- Solderjet Bumping for 3D components, sub-micron accuracy and stability
- Laser based thin film soldering for planar components
- Silicatic and plasma based bonding
- CO_2 laser based splicing and tapering of high power fiber components
- Classic wringing and clamping
- Adhesive bonding using tailored adhesives

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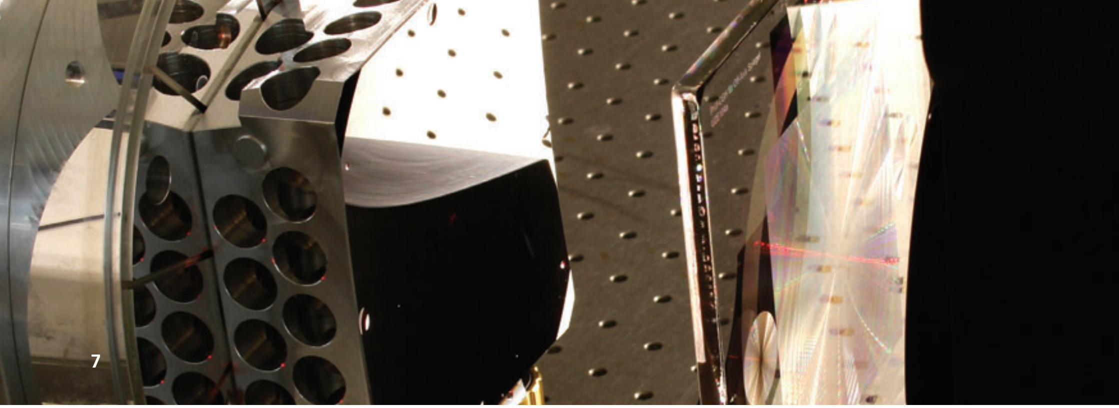

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OPTICAL AND TACTILE METROLOGY

7 Interferometric metrology of a free-form mirror with a Computer Generated Hologram.

The Fraunhofer IOF develops different optical and tactile metrology techniques for characterizing the optical performance of individual optics or optical systems with highest accuracy over a broad range of spatial frequencies. For determining the shape accuracy of high-precision optics interferometry, profilometry, and light projection methods are applied; for measuring the surface roughness with highest vertical resolution, AFM, WLI, LSM, and light scattering techniques are employed and combined.

- Shape characterization by high-precision profilometry, phase / wavelength shifting and highly dynamic interferometry
- Metrology of aspheres and freeforms with custom designed Computer Generated Holograms
- Data analysis / fusion using Power Spectral Density functions
- Determination of band-limited roughness, correlation length, etc.
- System testing and performance prediction based on light scattering models

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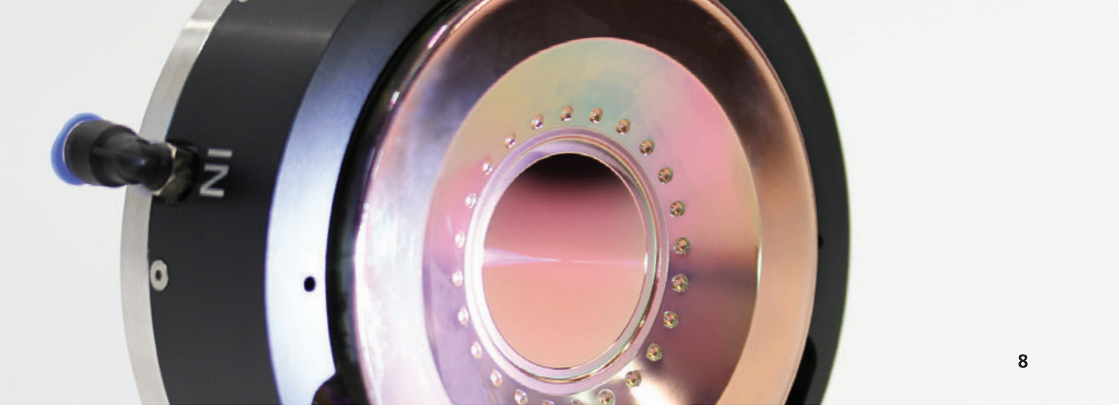

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ACTIVE OPTICS

Extensive experiences consist in design, testing, and commissioning of active optical systems. The Fraunhofer IOF develops thermal-piezoelectric unimorph deformable mirrors (DM) in order to compensate for wavefront aberrations in laser systems that are caused by thermal lensing or atmospheric turbulence. Technologies for the construction of space-qualified systems are available.

8 Thermal-piezo-electric unimorph deformable mirror to compensate for wavefront aberration.

In addition active systems with moveable lenses are used for changing optical system properties e.g. focus. Miniaturized solutions with large actuation range, high resolution, and low power consumption are developed. Active optics with potentially space-compatible packaging technologies can be provided.

- Thermal-piezoelectric unimorph DM wavefront compensation systems for high power optical systems ($2kW/cm^2$) or for atmospheric turbulence
- Focus-only DM with 2-meter focal length
- Piezomotor-based lens adjustment systems

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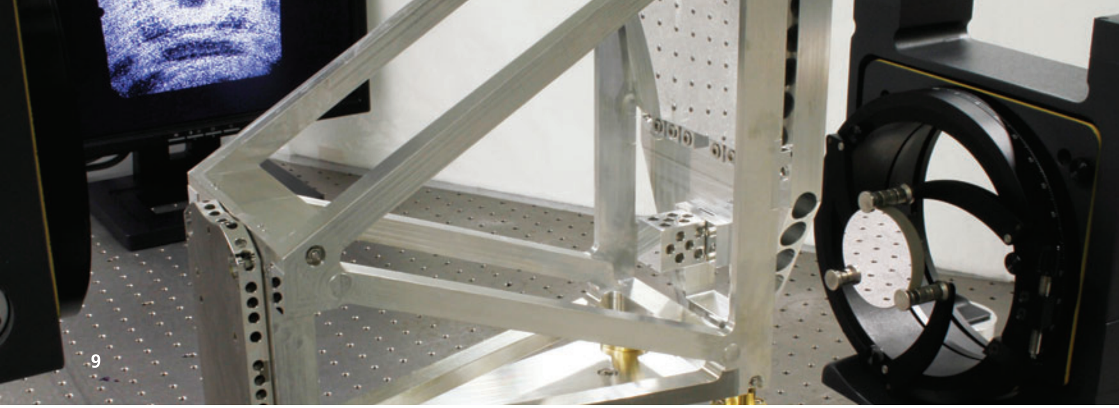

SYSTEM INTEGRATION

9 System integration of the IRSTEL telescope based of the snap-together system alignment.

A growing number of multi- and hyper-spectral imaging devices such as telescopes and spectrometers are based on all reflective metal optics. The assembly and alignment of each mirror in an imaging optics has to fit a tight tolerance range. Controlling the relative position of the optical elements with alignment steps with micrometer resolution and a few arcseconds of tilt error, respectively, is mandatory for diffraction limited imaging performance. The Fraunhofer IOF concept is based on an efficient and easy "Snap-together" alignment in combination with reference features which are cut with a diamond tool in the same fabrication step as the respective mirror surface.

- All-metal telescopes and spectrometers
- TMA telescopes for Earth observation
- Freeform based space optics
- Athermal optical systems
- Hybrid optical systems

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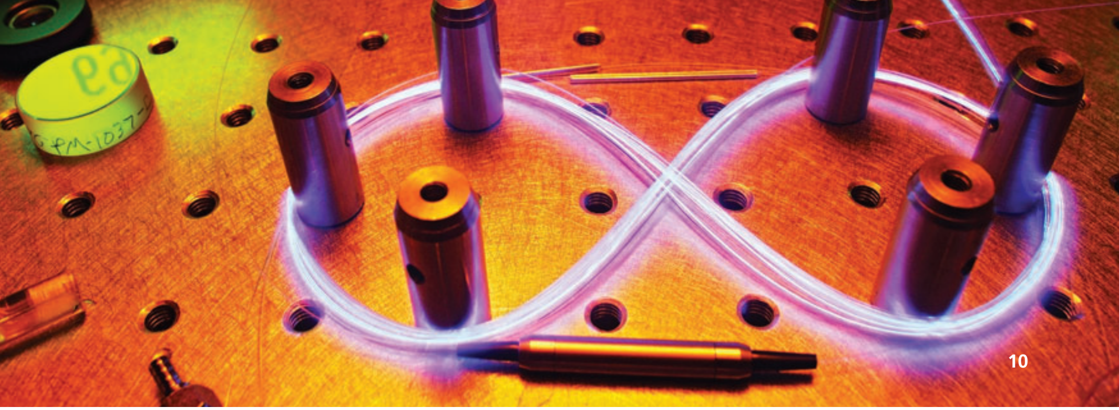

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FIBER LASER APPLICATIONS

Fiber lasers are getting more and more interesting for space applications in the fields of ranging and detection, communication, and earth observation. The Fraunhofer IOF is a partner for building high power fiber laser for harsh environments due to their inherent robustness and compact packaging based on qualified assembling and joining technologies.

10 High power fiber for ultra-short laser pulses.

- Laser development and qualification
- Assembling and joining technology
- Nonlinear optics
- Fiber design and fabrication
- Simulation and analysis

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