

# Institute of Technical Physics

Stuttgart



	Solid State Lasers and Nonlinear Optics TP-FN	Active Optical Systems TP-AO	High Energy Laser / COIL TP-HL	Studies and Concepts TP-SK
Standoff Detection	Pulse laser NLO	(Receiver) Optics	Trials, spectroscopy, data processing	System studies, risk reduction
Long Range Laser Effector	High power laser	Beam control	Propagation and target effects	Scenarios, system studies
Laser Propulsion	(Pulse) Laser	Transmitter optics beam control	Propagation	Mission studies, system concepts
Opt. Reconnaissance (Space Situational Awareness)	Pulse laser	Telescope, beam control	Atmospheric data, trials	Threat analysis, system studies

Structure of the institute: Key topics (rows) and departments (columns).

The **Institute of Technical Physics** is engaged in selected fields of optics and photonics. The work is primarily focused on aerospace issues and contributions to research in security and defence.

The Institute is divided into four departments – "Solid State Lasers and Nonlinear Optics", "Active Optical Systems", "High Energy Lasers / COIL (propagation and target effects)" and "Studies and Concepts". The main topics covered by the individual departments are represented in the second section of this brochure.

Based on the established expertise in the research fields of laser development and optical technologies and the many years of experience with activities and projects in the area of defence related research and technology, new research areas are addressed with regard to the demands of civil (security) research.

The Institute has identified new key topics which cover issues from both civilian and defence related research areas and thereby offer a priori a high dual use potential.

The bundling of the different expertise of the institute's departments in the key topic investigations also enables a high degree of synergy. The new key topics of the institute are:

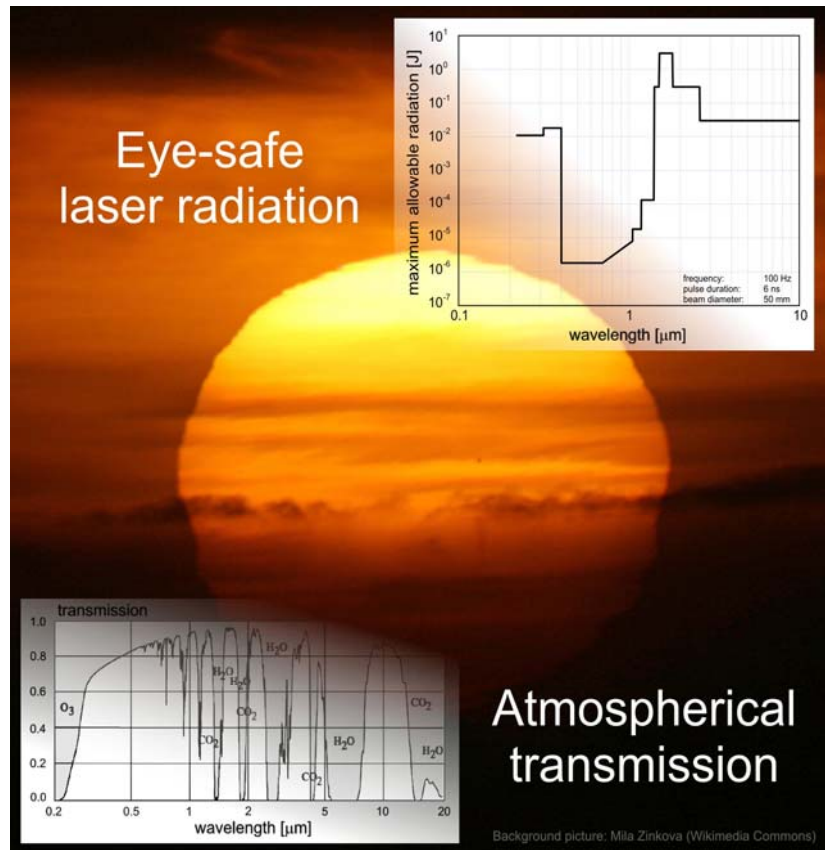
- Standoff detection, the recognition and identification of harmful and dangerous substances (chemical, biological, explosive)
- Laser effectors for beamed energy applications
- Laser propulsion, specific thrusters for space flight and
- Optical reconnaissance, high precision monitoring and assessment of the threats to satellites from space debris.

### Standoff Detection

The deliberate and unintentional release of chemical, biological, radioactive, nuclear or explosive (CBRNE) hazardous substances represents a threat to personal safety. They also pose a threat to civil security in conflict areas such as Afghanistan, where the security of the dispatched soldiers is currently jeopardised as a result of attacks. The urgent requirement for reliable verification procedures is accounted for by numerous nationally (German Federal Ministry of Education and Research, BMBF) and internationally (EU-FP7, EDA) funded research programs. Laser based standoff detection offers very promising possibilities for detecting and identifying hazardous substances at an early stage. As a result of a distance based, discreet and reliable detection procedure, countermeasures can be introduced in good time in the event of a crisis and the dangers reduced both for the general population and first responders.

The detection of hazardous substances is made more difficult by their diversity. The variety of distribution, contamination and incubation paths also increases the complexity of the problem. Chemical hazardous substances, such as the neurotoxin Sarin, are mostly distributed as a gas via air. Bacteria and viruses can attach to objects or disperse through air by aerosols. There they survive for several days and weeks. Explosive substances leave behind traces on surfaces, for example, in the form of fingerprints or as particles on textiles.

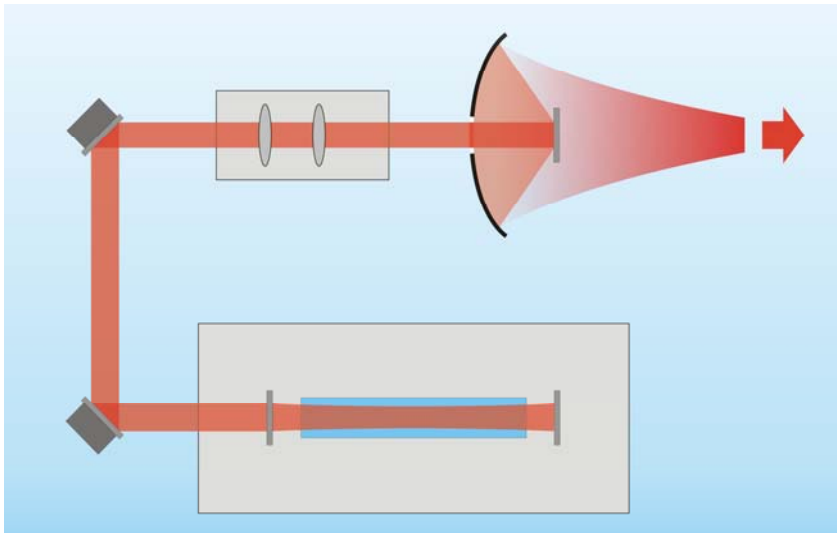
Many of the detection methods currently available require direct contact with the hazardous substance. This restriction makes an early detection difficult and cannot be carried out without risks to the assistants. Other methods limit themselves to distances in the metre range (portal systems) or are highly dependent on background radiation. Laser-based detection methods use various interaction mechanisms between electromagnetic radiation and matter. In this process, a large number of hazardous sub-



stances in various phases can be recorded over distances up to the kilometre range.

Eye safe laser radiation and atmospherical transmission.

The requirements on standoff detection under real operating conditions are characterised by the precise threat scenario and the current environmental conditions. Commensurate with the situation of danger, the systems are predominantly used in strenuous situations in which a rapid, discreet and above all definite detection of the hazardous substance is imperative. Danger to people as a result of the procedure itself must be excluded. The functionality is to be guaranteed within as well as outside buildings. To satisfy these requirements, laser radiation in the eye safe wavelength range is selected, thereby the optical transmission of the atmosphere has to be taken into account. Further influences on



**Components of a laser effector: bottom: laser radiation source, top: beam shaping and guiding.**

the atmosphere are a modified radiation background, restriction in visibility as a result of unfavourable weather conditions, smog or dust clouds, and the presence of natural trace substances that are similar to harmful ones. The development of compact, mobile complete solutions is the intended objective for rapid and effective operation in the crisis area.

At the Institute of Technical Physics the standoff detection of hazardous substances is investigated entirely. This also includes the development of suitable lasers as well as optical diagnostics and data analysis. The objective is to establish a procedure that is as simple and versatile as possible by evaluating the various methods under various operating conditions.

#### **Long Range Laser Effectors**

Focused laser radiation over shorter distances is an established tool for many applications such as laser materials processing and medicine. Using high power and high beam quality laser sources, it is also possible to transfer and focus energy over large distances. The alignment of the laser beam can thereby be easily and very rapidly controlled by tilting and tuning a reflector. For this reason such

long range laser effectors are particularly suited for hitting fast moving objects with laser radiation.

These properties open up a variety of applications. One example is power transmission using laser radiation for energy delivery – for instance for solar-powered unmanned aerial vehicles (UAVs) to make them usable at night. Even satellites could be supplied with energy in this way to compensate for the deterioration of solar cells, significantly increasing the mission duration.

Important safety applications for long range laser effectors include the protection of infrastructure against attack by mortar shells and missiles, and also the protection of aircrafts during take off or landing against surface-to-air missiles.

The beam shaping and guidance is a significant component of such a system. It must guarantee both optimum focusing of the beam onto the target and tracking of the beam on the target – even if the propagation through the atmosphere leads to marked disturbances in the beam position and beam profile.

For this purpose, methods are being developed at the Institute of Technical Physics for target tracking and the compensation of atmospheric disturbances. These methods are tested on a laser test range.

Specific requirements arise for the laser source for long range laser effectors:

- The emission wavelength must lie outside of atmospheric absorptions.
- The beam quality must be extremely high for optimum focusability.
- The effector system should be compact and efficient.

Based on currently available technology, diode pumped solid state lasers – in particular slab lasers, fibre lasers and disc lasers – are regarded as the best suited beam sources for this purpose. At present fibre lasers offer the highest output

power with excellent beam quality, however, the maximum output power of a single fibre is limited.

Current research at the Institute of Technical Physics is focused on the radiation sources, the development of compact high powered disc lasers and on concepts to couple several laser sources.

### Laser Propulsion

The principle of laser propulsion has been demonstrated worldwide in numerous terrestrial experiments. The initial goal of thermal laser propulsion investigations was the development of an alternative propulsion concept for the launch of small satellites (nanosats) from the Earth's surface into low Earth orbit (LEO). However, the pulsed laser output required for this is not available in the short and medium term.

Based on advances in the field of solid state laser technology which permit the development of more powerful, compact pulsed laser sources even for application in space and zero gravity environments, laser propulsion offers new possibilities for the position keeping and attitude control of satellites or satellite constellations in orbit. Beam guidance and control based on active optical systems enable remote laser propulsion applications. Therefore, in a further step, missions with small probes are conceivable, for instance to "take samples" on asteroids or (small) planets and to return on a "tractor beam".

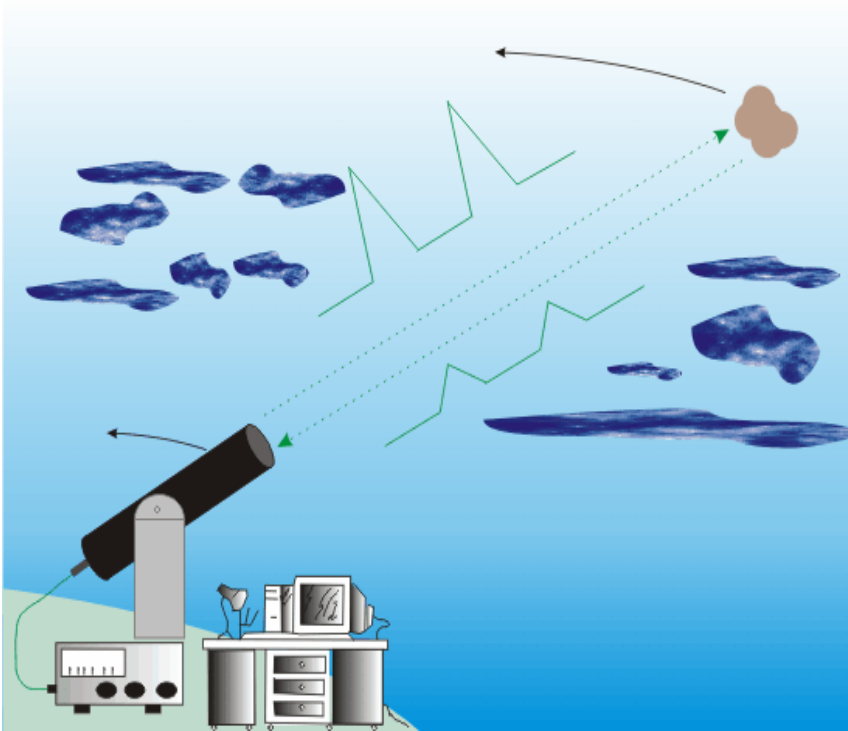
The latest research objective is the development and qualification of highly precise thrusters with thrusts levels in the range of 0.1  $\mu\text{N}$  to 1 mN. Alternative micro propulsion concepts which are necessary for many missions with precise position and orbit control are urgently required. A growing need has not only arisen in the case of geodetic missions to measure the Earth's gravitational field (follow-up missions to CHAMP, GRACE or GOCE) or astronomical missions for X-ray astronomy in which the telescopes are made of two satellites with highly precise distance control (up to 50 m), but



Schematic view on the launch of a small satellite by a ground based high energy laser.

also for astronomical projects which require greater formations (such as Darwin).

Laser propulsion is ideally suited to micro propulsion as a result of its high precision and very simple (propellant) infrastructure. Laser induced ablation of metals or composites with pulsed laser sources is a promising technology to provide a new type of thrusters with highly precise thrust control.



**Schematic of laser ranging and tracking of space debris in LEO.**

**Optical Reconnaissance (Space Situational Awareness)**

The constant increase in the number of space missions has led to a high density of so called "space debris". This space debris is the result of explosions of missile upper stages, surface degradations based on the harsh conditions in space and satellite collisions.

As a result of radar based and passive optical observations and computer simulations, the determination of the height-dependent distribution of space debris items is possible. In LEO (Low Earth Orbit) at 900 km and 1400 km and in GEO (Geosynchronous Orbit), an accumulation of these objects has been determined. This results in an increased risk to the infrastructure located there, such as communication satellites in LEO. If the population exceeds a critical threshold value, a cascade effect is imminent whereby the debris objects continue to

multiply as a result of inter debris collisions.

A first step in avoiding damage to satellite systems is achieved by the exact and comprehensive recording of the trajectory data of all critical objects with dimensions larger than 1 cm. As a result of the non predictable influences that act in orbit on the debris trajectories, such as atmospheric friction or solar particle radiation, the trajectory data must be updated in the event of imminent collisions.

To be able to determine this trajectory data with a high level of efficiency and accuracy, laser based methods are combined with passive optical tracking techniques. Debris objects are initially detected with an observation telescope using solar illumination and are then actively illuminated. Methods for target tracking and for the compensation of atmospheric turbulence effects are being developed for this purpose. Simulation calculations for the laser beam propagation in turbulent atmosphere support the design of a system. These methods are then tested on a laser test range under horizontal propagation. The development of a suitable laser source with high beam quality, pulse energy and repetition rates in the kHz range is running in parallel. This system will be adapted for operation in the field after successful functional verification in the laboratory.

The initial objective is the setup and operation of a "space debris monitoring platform". Later on, when the relevant high power lasers are available, it will be possible to remove centimeter class space debris using laser based methods.

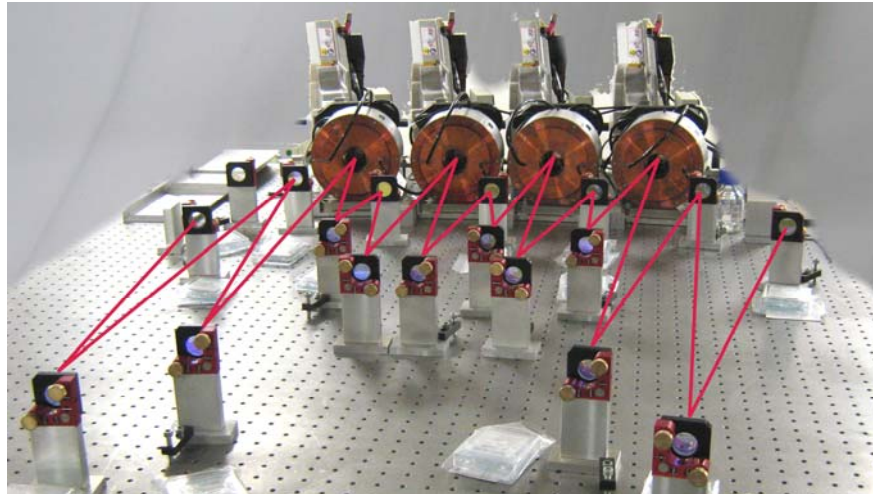
## Solid State Lasers and Nonlinear Optics (TP-FN)

The task of the Solid State Lasers and Nonlinear Optics department is the development and adaptation of laser radiation sources for application in aerospace as well as security and defence applications. Some of these applications require sources of the highest power and beam quality – for example for energy transmission via laser ("power beaming") or the interception of mortar grenades and missiles. For other areas of application, laser sources are required which combine wavelength selectability with a high frequency stability, for e.g. remote detection of harmful and hazardous substances, for atmospheric research or for optical communication.

### High power lasers

For the development of powerful laser sources with high beam quality, the activities are focused on concepts based on the thin disk laser. These diode pumped solid-state lasers combine power scalability with excellent brilliancy and high efficiency. The laser active medium consists of an extremely thin crystal disc (only a few hundred micrometres thick), which is cooled on the back surface. This enables extremely high pump power densities with minimised thermal lensing effects. The power scaling can be carried out for instance by enlarging the active surface at a constant pump power density. Here, both the temperature in the disk and the necessary brilliancy of the pump diodes remain constant.

Today, industrial thin disc lasers are available with up to 16 kW continuous output power. These lasers typically operate in multi mode with  $M^2 > 20$ . The Institute of Technical Physics focuses its work on the verification of the power



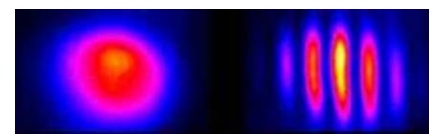
scalability of thin disk lasers with virtually diffraction limited beam quality up to the highest power range.

Experiment for the coupling of four laser disks in one resonator, output power up to 3 kW.

### Coherent coupling

The coupling of several lasers is a concept for dealing with the power limitations of single sources. In the geometric coupling of independent laser sources the beam quality worsens markedly in comparison with the single source. However, if the laser sources are coupled in such a way that the phase relationships of the single sources are constant, this is called coherent coupling. The coupled laser sources then behave as if they were sub apertures of a sole laser source and their beam quality is that of the single sources.

At the Institute of Technical Physics, the coupling of master oscillator power amplifier systems (MOPAs) with active phase control is being investigated. Using such a system, the coherent coupling of several fibre lasers was demonstrated.



Coherent coupling of fibre lasers, left: without phase control, right: with phase control.

### Nonlinear optics

Tried and tested and efficient solid state laser materials are only available for a few wavelength ranges, and typically these lasers emit in the near infrared region. To verify harmful and hazardous substances or to detect atmospheric trace gases, however, UV sources for laser induced fluorescence (LIF) detection and sources in the mid infrared region for absorption measurements on rotational and vibrational transitions of molecules are particularly suitable. To be able to generate radiation with these wavelengths and with the necessary frequency stability, the FN department investigates different methods of nonlinear frequency conversion and develops these in a targeted manner for the respective applications. This includes frequency multiplication, the generation of sum frequency and difference frequency and the use of optical parametric oscillators and amplifiers.

### Directed optical countermeasures

A field of application of nonlinear frequency conversion relevant to security is the interception of missiles equipped with heat seeking heads. In some scenarios, radiation sources are required that deliver high laser power or high pulse energy in the wavelength ranges used by these seeker heads. Suitable solid state laser sources do not exist for this purpose, therefore the FN department is investigating methods of nonlinear frequency conversion for these wavelength ranges.

### Pulsed laser

For many methods of remote detection pulsed radiation sources are necessary, both to achieve the necessary intensities and to obtain distance information via time-of-flight measurements. Furthermore, nonlinear frequency conversion generally requires pulsed pump lasers. In particular, lasers that combine high pulse energy with high average power and good beam quality are not commercially available and are therefore being developed by the Institute of Technical Physics.

High pulse energies ( $> 1 \text{ J}$ ) and high average powers ( $> 1 \text{ kW}$ ) are necessary, for example, for determining the distance to small objects that are far away using pulsed time-of-flight measurements – for instance to detect so called space debris. In this way, extremely accurate trajectory data of these particles can be determined with short measurement times. If the pulse energies are increased further, space debris cannot only be detected but, by using laser ablation, can be slowed down to such an extent that it finally burns up in the atmosphere.

Such pulsed laser sources with high power and high pulse energy are being developed in the FN department using the thin disk laser as a basis. Particularly advantageous here is the possibility of scaling the power by enlarging the active surface: both the pulse energy per surface area and the pulse peak intensity remain uncritical in this scaling.

### Laser sources for emission wavelengths $> 1.4 \mu\text{m}$

The risk to eyes from laser radiation with wavelengths greater than  $1.4 \mu\text{m}$  is markedly lower since this radiation is not focused onto the retina. Applications such as LIDAR measurements for atmospheric research or standoff detection can be carried out at a reduced risk potential. This also results in lower requirements for screening scattered radiation for laser material processing. In addition, many procedures for frequency conversion in the mid infrared range require long wavelength pump lasers.

An example of a successful implementation of an efficient and scalable laser source with an emission wavelength of  $2 \mu\text{m}$  is the Ho:YAG thin disk laser, which was developed at the Institute of Technical Physics. This laser also features the potential to generate high pulse energies.

Another category of laser materials being investigated is compound semiconductors doped with transition metals, in particular Cr:ZnSe. This material offers

a very broad amplification spectrum between  $2 \mu\text{m}$  and  $3 \mu\text{m}$ . It is thereby particularly suited for laser sources such as those required for remote detection applications which are based on the measurement of molecular rotational and vibrational transitions.

## Active Optical Systems (TP-AO)

**Atmospheric turbulence adversely affects the propagation of laser radiation, in particular within the boundary layer near to the ground. In the Active Optical Systems (TP-AO) department, systems are being developed which aim to compensate for this atmospheric interference for emitting laser radiation and for imaging objects under active laser illumination.**

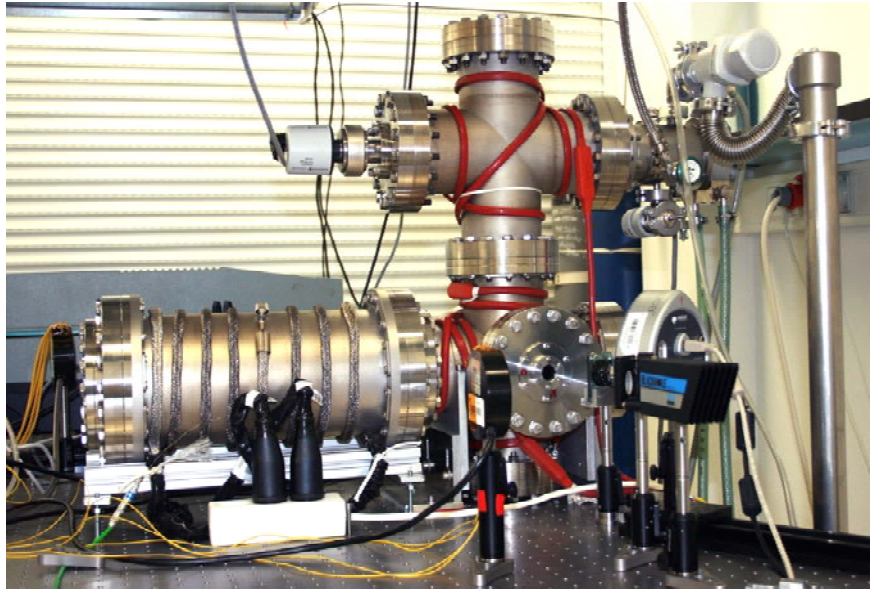
**A second area of activities is the qualification of laser optics for application in high power lasers or for use in orbit. For this purpose, optics are subjected to damage threshold tests which comply with international standards. Nonlinear optical crystals are compared with regard to their conversion efficiency and radiation resistance under proton and gamma radiation. Furthermore, investigations on laser induced contamination are carried out.**

**Atmospheric real time laser tracking**  
The detection and continuous tracking of fast flying distant objects such as UAVs or space debris requires highly precise and sensitive tracking systems which feature accuracies in the sub  $\mu\text{rad}$  range and bandwidths in the kHz range. These requirements arise from the unavoidable air turbulence in the atmosphere which can lead to a destabilisation of the centroid position of a laser beam and consequently to a reduced power density at the target. Further disturbance of the

beam direction is caused by vibrations of the mounting of the transmission optics. The typical time constants for variation of atmospheric turbulence cells lie in the range from 10 to 100 ms. Subject to existing meteorological conditions, angles of deflection of up to 100  $\mu$ rad occur.

The laser tracking systems developed in the TP-AO department fulfil these requirements and, moreover, are real time capable. The systems are based on commercially available adjustable reflectors with piezo driven actuators. Highly sensitive quadrant diodes with amplifier electronics developed by the department are used as position sensors. A compact laser tracking unit has been successfully adapted to a 10 inch Schmidt-Cassegrain reflector telescope, in order to conduct tracking experiments over large distances. To analyse the suitability in the field, a number of tests were carried out on the Institute of Technical Physics' laser test range. In these tests, over a propagation length of 130 m, a beam direction instability of 6  $\mu$ rad (standard deviation) related to turbulence was successfully reduced to less than 300 nrad. This equates to a position fluctuation of about 1 mm over a distance of 3 km.

The data obtained in atmospheric tracking experiments permits the scaling of the system requirements to relevant distances of several kilometres. Furthermore, the basis is thereby laid to track satellites and space debris in their trajectories in LEO and GEO in a highly precise manner and to enable scientists to determine the corresponding trajectory data.



#### **Atmospheric compensated imaging**

In addition to excellent imaging properties, high resolution telescope systems also require as large an entrance pupil as possible to improve the diffraction related resolution. As a result of wind, air pressure and temperature differences, turbulences arise in the optical path which can vary the refraction index within the beam cross section and as a function of time. This results in an enlargement of the minimum possible diffraction spot which leads to a loss of image detail. Adaptive optics can reduce these limitations.

A mobile demonstration system was developed to verify the compensation of local turbulence. In this system, a fast Shack-Hartmann wavefront sensor (bandwidth 1 kHz, 16 x 16 microlens array) and an adaptive membrane reflector with 52 actuators are used. Using this system, the compensation of local turbulence was successfully demonstrated. However, it appeared that the compensation of volume distributed turbulence on the laser test range was far less successful. This is due to the strong requirements on the spatial resolution and

**UHV contamination facility for the testing of ATLID outcoupling windows for the ESA EarthCARE mission.**



**A mobile adaptive optics demonstration system used for high resolution imaging.**

the bandwidth of the wavefront sensor and the adaptive reflector. At the same time, the isoplanatic angle restricts the effective image area. Multi-conjugate adaptive optical methods or iterative optimisation algorithms offer a new approach to better fulfil these requirements in the future. A complete compensation of volume distributed turbulence is, however, not possible using the approaches available at present.

#### **Test centre for laser optics**

Both in the civil and defence technology domain, the development of compact laser systems with high performance requires the availability of laser optics with high damage thresholds. Against this background, the TP-AO department operates a test facility to qualify laser optics and optronic components to investigate, in particular, multiple pulse damage thresholds. Furthermore, laser induced damage processes are also analysed and evaluated. This forms a prerequisite for the development of methods for the protection against laser radiation. This work is also carried out as a service for external customers. The damage thresholds are determined under class 1000 cleanroom conditions according to the international standard ISO 11254-2. The tests are carried out at prominent Nd:YAG laser wavelengths in the infrared (1064 nm), visible (532 nm) and ultraviolet (355 nm) at pulse durations of a few nanoseconds. All the tests on optical components can be conducted both under standard atmosphere and under vacuum conditions in order to simulate conditions in orbit. The German Aerospace Centre's damage threshold test facility qualifies all the relevant laser optics for the upcoming ESA missions (ADM Aeolus and EarthCARE).

#### **Qualification of frequency conversion crystals**

Nonlinear optical crystals are important components of many laser systems. Prior to using such crystals in space, it must be clarified whether their optical properties will be negatively influenced by the omnipresent cosmic radiation. As part of

an ESA project, extensive investigations are also carried out with different frequency doubling and frequency tripling crystals. For the investigations, the crystals were exposed in several steps to high energetic proton and gamma radiation.

In addition to the irradiation test, extensive long term efficiency measurements for frequency doubling and tripling are also carried out. The objective is to determine the optimum crystals for application in space and to achieve an optical efficiency of higher than 30 % for generating laser radiation at 355 nm.

#### **Laser induced contamination**

For the use of laser systems in space, laser induced contamination plays a disreputable role since several NASA missions such as LITE, MOLA and ICESAT have failed or have not been completed as planned for this reason. Laser induced contamination is caused by the emission of organic and inorganic molecules of adhesives, insulating materials or conductor plates. Although in principle only components with a low gas emission rate (TML (total mass loss) < 1 %; CVCM (collected volatile condensable material) < 0.1 %) are permitted, and these materials are conditioned by prior baking for use in space, it is not possible to completely prevent outgassing. If the outgassed molecules interact with laser radiation, the result is decomposition and deposition of the residues on the optics. This occurs in particular if intensive radiation in the short wavelength range is concerned. Even the smallest deposits with a thickness of a few nanometres can decrease transmission such that the lifespan of the entire laser system is markedly reduced or even threatened with system failure. Laser induced contamination occurs particularly in vacuum though it can also adversely affect the lifespan of encapsulated pressurized laser systems.

To avoid or considerably minimise such risks, fundamental investigations on the origin and growth of such deposits are necessary. The TP-AO department oper-

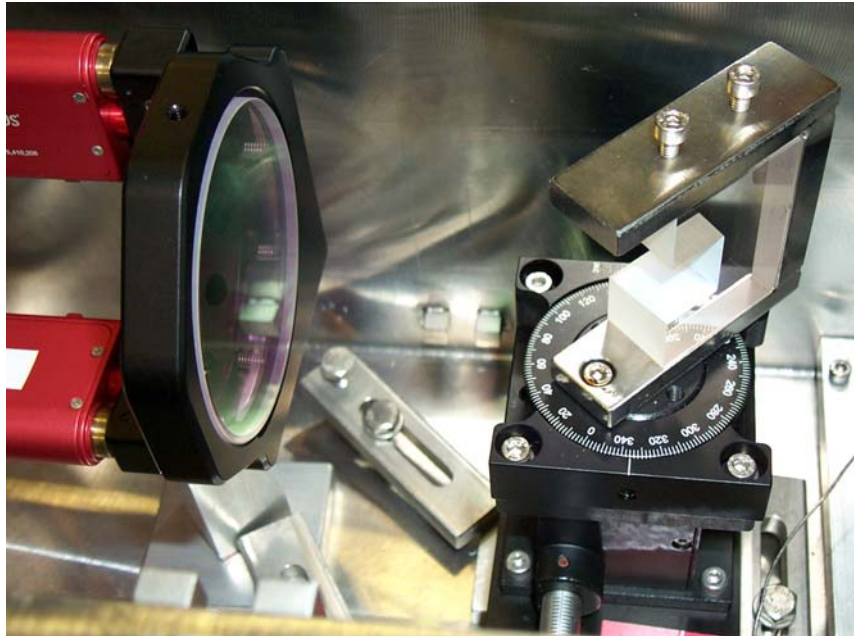
ates ultra high vacuum contamination facilities on behalf of the European Space Agency (ESA) to screen materials to be used in space. In addition, methods are developed to prevent the molecular transport or the attachment to optics.

## High Energy Lasers / COIL (TP-HL)

**The High Energy Laser / COIL department is concerned with the generation of highly brilliant laser radiation and the investigation of the propagation and effect of laser beams under real atmospheric conditions for selected areas of application. The current research work is focused on the development and assessment of laser based techniques for the standoff detection of harmful and hazardous substances.**

### High energy lasers

The efficient long range effect of laser radiation requires powerful beam sources with high levels of brilliance, which also offer good transmission through the atmosphere. At the Lampoldshausen site, research and development work is carried out on and with the chemical oxygen iodine laser (COIL). With its outstanding scaling properties, its high efficiency, its homogenous amplification medium and its wavelength at  $1.315 \mu\text{m}$ , COIL provides the optimum prerequisites for applications in the high energy field. With up to a 13 kW power output, the institute operates the most powerful laser of this kind in Europe.



### Resonator development

For high energy lasers with weakly amplifying laser active media, pioneering field capable resonator concepts are designed and evaluated in numerical studies. The investigations for power and beam quality which can be achieved, are orientated on the propagation properties of the laser radiation in the free atmosphere.

The design and simulation of new resonators is carried out numerically. The basis of these calculations is the integral equation of the Fresnel-Kirchhoff formulation of Huygens' principle. Promising resonator architectures are used amongst others on the chemical oxygen iodine laser and optimised with regard to their outcoupling properties. The experimental validation also forms the basis for scaling calculations on laser systems of higher and the uppermost power classes.

**Resonator for uppermost power classes: MNBUR (Modified Negative Branch Confocal Unstable Resonator) with scraper.**



**Laser based standoff detection at the free space optical test range.**

**Laser test range**

The long range effect of laser radiation is substantially influenced by atmospheric properties and can therefore only be derived to a limited extent using conventional laboratory investigations. To provide reliable basics, investigations must be carried out on the beam propagation and beam effect under real atmospheric conditions (solar irradiation, weather).

At the Lampoldshausen site, a laser test range has been designed and built for experimental investigations on laser beam propagation. In terms of its supply and measurement technology, this test bed is equipped for a broad spectrum of applications. A well engineered basic concept makes it possible to incorporate the most diverse types of lasers and measurement processes as well as complex receiving systems. The latest video and control technology complement structural laser safety measures and permit comprehensive experimental monitoring and detailed experimental information. In addition to the institute's internal work on laser beam propagation, the test range facilities (structure and environmental diagnostics, optionally also available laser systems) are also

available to customers and can be adapted to their requirements.

**Turbulence diagnostics and micrometeorology**

In order to assess the results on the atmospheric propagation and long range effects, the current atmospheric properties must be appropriately taken into account. A continuous weather measurement technology tailored to the issues of atmospheric propagation and ongoing topographical investigations on the behaviour of optical turbulence near ground level allow the inclusion of local conditions in the national and international framework.

**Atmospheric propagation**

The investigations regarding the propagation of high power laser radiation are supplemented with experiments on the propagation behaviour of laser beams of different wavelengths and power densities. The experimental work is accompanied by numerical studies on the description of atmospheric propagation. In addition, simulation models are used which are developed internally and enhanced on an ongoing basis. Moreover, commercial software packages for singular issues are available. Experimentally confirmed results serve the basis for simulation calculations for additional tasks like imaging and tracking and for the cross departmental topics of "long range laser effectors" and "optical reconnaissance (space situational awareness)".

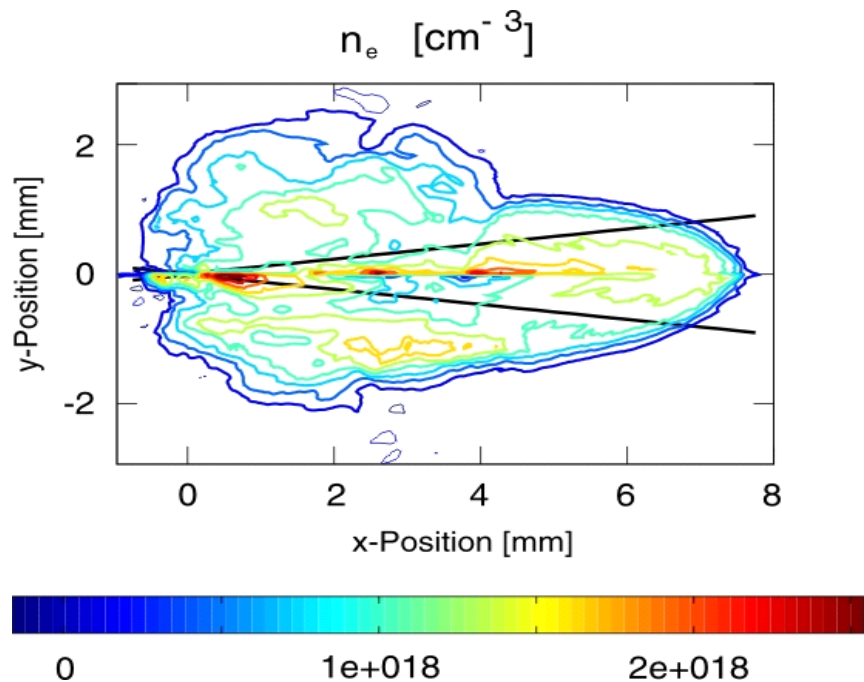
### Effect

The effect of high energy radiation on target structures is diagnosed by various measurement methods. In addition to conventional video technology as well as spatial and temporal temperature profile measurement, this also includes infrared and high velocity videography of stationary and moving targets. Besides laboratory investigations, there are a series of tests to evaluate the long range effect of lasers on stationary and moving objects, thus giving results about the influence of the atmosphere on the laser effect on the target. The detailed information that is derived from this represents the basis for specifying the requirements for efficient tracking systems.

### Laser based standoff detection

As part of security research, this main research aim addresses integrative systems for the detection of harmful and hazardous substances on surfaces or in the air. In contrast to the research and development work on the long range effect of continuous laser radiation, pulsed high power lasers are used for this application.

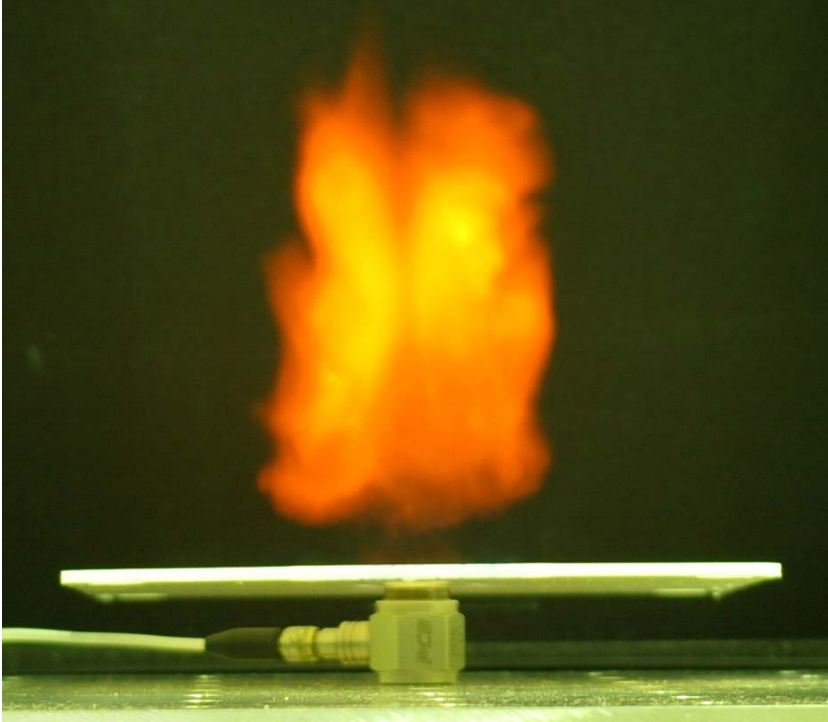
In the Institute of Technical Physics, there is experience in long range detection of gaseous substances. Examples of this are the detection of methane gas in the surroundings of a possible leakage in a natural gas pipeline (CHARM) or the detection of water vapour concentration in the atmosphere (WALES). For the standoff detection it is primarily the determination and recognition of unexpected substances that represents a challenge in the detection and identification methods. Owing to the multitude of possible hazardous substances, a combination of different measurement processes is used for an early and reliable detection of potential states of risk. For a thorough description of the situation, different kinds of contact free and discreet standoff detection diagnostics are considered and their practicality is assessed: LIDAR (light detection and ranging), DIAL (differential absorption), LIF (laser induced fluorescence), Raman



spectroscopy and also LIBS (laser induced breakdown spectroscopy) especially for applications of surfaces contaminations. All processes take advantage of the fact that laser light is dispersed, absorbed or re-emitted by matter. The returning radiation is picked up using a telescope and investigated with respect to its intensity, polarisation and spectral distribution. In comparison with existing databases any existing hazardous substances can then be classified or even identified.

**Interferometrically determined electron density  $n_e$  of a stable, laser sustained Argon plasma.**

As part of the first validation investigations on the laser test range, gold in the nanogram range could be detected using the LIBS method on surfaces at a distance of 50 m. As an example of an explosive substance, at a 130 m distance, a metal surface coated with gunpowder was hit with laser radiation. Even in the event of extreme solar irradiation, the substance  $\text{KNO}_3$  contained in the gunpowder was diagnosed in a single pulse.



Measurement of momentum transfer by laser induced ablation.

## Studies & Concepts (TP-SK)

**The Studies & Concepts department is concerned with experimental and theoretical studies on specific tasks and applications of laser systems that have already been explored in principle as well as conceptual study investigations on the design and application potential of new laser systems.**

**Particularly relevant to aerospace are the experimental studies on laser induced flow control and laser propulsion.**

### Studies

Concept studies generally focus not only on the technical, but also on the overall system aspects of (defence technology-relevant) laser applications. The analysis and assessment of the performance of laser-active materials and nonlinear

optical components also plays an important role.

Further activity includes analyses of the potential threat as a result of laser radiation in various scenarios.

### Laser induced flow control

The active control of a technical flow is a promising technology for reduction of aerodynamic drag.

For example, it is possible to induce a modification of the shock wave structures as a result of an energy deposition in the flow field of a supersonic missile, reducing the wave drag. The drag reduction that has been proven by experimental investigations and numerical modelling is caused by local heating of the gas flow.

The objective of the investigations is the energy deposition by laser induced plasma. The ionization of the gas in the focus of the laser beam induces an efficient absorption of the incoming laser radiation, creating a plasma, and leading to an intense heating of the gas volume.

The energetic and dynamic characterisation of the energy deposition is carried out on the basis of optical diagnostics. As a result of interferometric measurements, density differences in the measurement volumes can be ascertained which give information on the electron density ( $n_e$ ) in the plasma and the slow thermal heat conduction process.

### Laser propulsion

The work on laser propulsion at the Institute of Technical Physics covers both basic investigations on pulsed thermal laser propulsion with stationary high power laser sources and the development and qualification of laser ablation based micro rockets.

The principle of thermal laser propulsion is based on a repetitively pulsed propulsion mechanism. A thrust chamber in the form of a parabolic reflector concentrates the received laser energy into the focal spot. There, from the propellant, for

example air, a high density plasma is formed, which detonates and rapidly expands. A spherical shockwave is produced at high pressure and high temperature, which accelerates the gas. By means of a metallic ignition pin on the axis of symmetry of the thrust chamber, a consistent reproducible ignition of the detonation process is ensured. High speed camera recordings of pulsed free flights of the laser rocket indicate that the craft exhibits beam riding properties within certain limits of lateral offset and inclination. Based on calculations of the intensity distribution inside the thrust chamber this highly nonlinear dynamic system and the resulting forces have been numerically modelled. Thus suitable starting parameters for stable flight as well as critical boundary conditions can be derived by the calculations. Active flight control has been implemented by tilting the ignition pin or the propellant cylinder with respect to the axis of symmetry of the thrust chamber.

For micro propulsion by laser ablation the (compact) laser source is integrated in the thruster device. The thrust is generated as a result of the recoil of the ablated propellant.

Precise thrusters require highly accurate impulse bits and high specific impulse. Different metallic propellants made from aluminium to gold are promising candidates to meet these requirements.

Experimental investigations are carried out at a test bed employing a solid state laser. The experiments are supported and complemented by theoretical calculations on the propulsion process. The experimental setup includes a highly sensitive thrust gauge under vacuum conditions as well as devices for the analysis of the expansion velocity of the ablation jet. The development of an active optical system that allows for momentum conserving beam steering across the target surface is a prerequisite for the vibration free integration of the thruster in the satellite system. For future missions the long term stability and the reproducibility of the

system performance have to be proven in extended endurance tests.

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