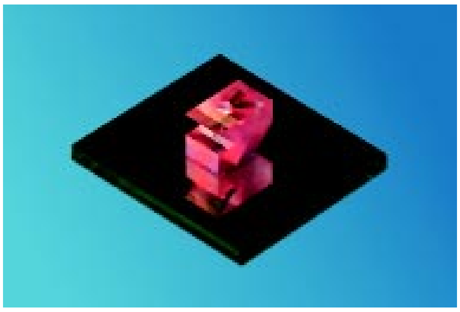
Fraunhofer Institut Angewandte Optik und Feinmechanik

Annual Report 2001



Annual Report 2001
Fraunhofer Institute for Applied Optics and Precision Engeering IOF

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Fraunhofer-Institut für
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Preface

Dear Reader,

2001 has been a strenuous but successful year for the Fraunhofer IOF staff. The growing number of projects and orders from industry led to a considerable additional operations volume, which could only be partially controlled by an increase of nearly ten per cent of personnel. Unfortunately, we also had to suffer from the fact that there were not enough professionally very well trained young scientists and engineers who can take up the challenges of future technologies and their respective fields of application.

The cooperation with enterprises has grown especially strongly. In this context, it should be mentioned that about half of our industrial projects are done with Thuringian firms. Here the Fraunhofer IOF fulfils one of its tasks, namely, to support the regional economy. On the other hand, we have achieved visible progress in the international cooperation with industry. This is reflected in the increased cooperation in EU projects as well as contracts with overseas companies in highly application-relevant fields of optical technologies.

During this term (in 2001), the Fraunhofer IOF's core competences were further developed with regard to quality and quantity. This applies, in particular, to the sphere of optical coatings and in the measurement and characterization of coatings and surfaces, and also in the field of micro-optics and its applications. The intensive development of the optical 3-D measuring technology during the last few years has led to prototypes of a group of instruments suitable for industry, which has successfully stood the test in different kinds of branches, and especially in harsh environment. The constantly expanded know-how in precision mechanics was also taken into full recognition during the last year resulting in very comprehensive orders for the automation of the assembly of photonic components.

In the autumn of 2001, the Fraunhofer IOF underwent an audit by high-ranking representatives from trade, industry and science. Apart from a critical self-scrutiny of the Institute, the external examination produced a number of extremely helpful suggestions and hints for the further strategic adjustment and strengthening of the Institute, both scientifically and economically.

The Institute is closely integrated into the region's scientific community. On a national basis, the Fraunhofer IOF also cooperates closely with many universities and other institutions and expands its international relations in many areas.

The Fraunhofer IOF has been active in the integrating and initiating of the optics network of the region, where many companies and scientific institutions assemble.

Once again, our thanks go to our partners in industry and scientific institutions for their good cooperation; to the Federal Ministry of Education and Research, as well as the Thuringian Ministry of Science, Research and Art for their continual support.

We also thank all the Fraunhofer IOF staff for their dedicated work, the commitment to their professional tasks and the often high demands made on their time.

W. Karthe

Jena, January 2002

Profile

The Fraunhofer Institute for Applied Optics and Precision Engineering IOF is engaged in research and development in the fields of optical and mechanical processes, components, modules and systems.
We develop, fabricate and characterize ultrastable metal/dielectric coatings for optical radiation (up to the extreme UV) of high energy densities, and micro-optical and integrated optical components of glass, Si and polymers, and we upgrade methods for non-contacting optical 3-D form measurement and surface topography acquisition. Our competences include the designing of precision mechanical systems, precision manipulators and medical instruments, and the development of assembly processes including those for microsystems.

Fields of Work

The Fraunhofer Institute for Applied Optics and Precision Engineering IOF develops and designs optical and mechanical processes, components, modules and systems. Our main fields of activity are components and subsystems for optical information, laser and illuminating technologies; optical testing and measuring methods including optical sensors; modules for precision mechanical systems; optical coatings, and optical instruments and techniques for medical diagnosis and therapy. The projects carried out in these fields are supported by our core competences: Design and analysis of optical and optomechanical systems, micro-optical technologies and systems, optical shape and surface testing, and optical coating.
We design, for example, ultrastable multilayer dielectric/metal interference filters for the visible, ultraviolet, and soft x-ray wavelength ranges down to 1 nm and for energy densities up to 30 J/cm², and develop the processes for their manufacture.
Micro-optical and integrated optical components designed at the Fraunhofer IOF, made of plastic materials, silicon or glass, are largely used in industry. Miniaturized optomechanical systems and passive and active components developed at the Fraunhofer IOF are employed in tele- and data communication, sensor technology, and in manufacturing, medical and environmental technologies.
Optical measurement methods including non-contacting 3-D form measurement and surface defect characterization developed at the Fraunhofer IOF are used in industrial applications like Reverse Engineering, dental technique, automotive and airplane system developing, optical element construction, and quality management systems.
In collaboration with, and under contracts from, industrial corporations the institute develops and designs precision mechanical systems, e.g. for precise manipulators and top-resolution lithographic machines, and develops assembly techniques for optical and micromechanical systems.
The projects carried out at the Fraunhofer IOF include methods and equipment for the measurement and testing of the components mentioned, and the manufacture of prototypes and preproduction test series.
By engaging the Fraunhofer IOF's collaboration, industrial clients can enhance their manufacturing capabilities and create new products for the market.
The institute is partly funded by state, federal and EU projects. Its permanent staff of 90 and about as many temporary staff work in laboratories and offices totalling about 3000 m² of floor space.

Profile

Le Fraunhofer-Institut d'Optique appliquée et de mécanique de précision IOF est spécialisé dans la recherche et le développement dans les secteurs de l'optique et des procédés mécaniques, l'élaboration de composants, de modules et de systèmes.
Nous développons, fabriquons et caractérisons des traitements métal/diélectrique d'une extrême stabilité (jusque dans l'EUV) aux hautes énergies, des composants d'optique intégrés et de micro optique sur verre, Si et polymères et nous parachevons des méthodes de mesures optiques 3-D sans contact ainsi que des acquisitions de topographie de surfaces. Nos compétences incluent le design des systèmes mécaniques de précision, les manipulateurs de précision, les instruments médicaux et le développement et l'assemblage de procédés incluant ceux pour micro systèmes.

Secteurs d'activités

Le Fraunhofer-Institut d'Optique appliquée et de mécanique de précision IOF conçoit et développe des procédés optiques et mécaniques, des composants, des modules et des systèmes. Nos principaux secteurs d'activités sont les composants et les systèmes d'information optique, les lasers et les technologies d'éclairage, les méthodes de mesures et de tests optiques incluant les détecteurs optiques; les modules pour les systèmes mécaniques de précision; les traitements optiques, et – dans une plus large mesure – les instruments et techniques optiques pour les thérapies et diagnostiques médicaux. Les projets menés à bien dans ces secteurs sont le fruit du fleuron de nos compétences: l'analyse et le design de systèmes optiques et opto mécaniques, les systèmes et technologies de la micro optique, les tests optiques de surfaces et de contours, et les couches minces optiques. Nous fabriquons, à titre d'exemple, des filtres interférentiels multicouches métal/diélectrique pour le visible, l'ultraviolet et les rayons X mous jusqu'à des longueurs d'onde de 1 nm et résistants à des densités d'énergie de 30 J/cm², et développons les procédés pour les fabriquer.
Les composants d'optique intégrés et de micro optique produits à Fraunhofer IOF, sur verre, silicium ou sur matériaux plastiques, sont largement utilisés dans l'industrie. Les systèmes opto mécaniques et les composants passifs ou actifs développés à Fraunhofer IOF sont employés dans la télé- et data communication, les technologies des capteurs, dans la manufacture, les technologies médicales et de l'environnement.

Les méthodes optiques développées à Fraunhofer IOF, telle que les mesures sans contact de forme 3D et la caractérisation des défauts de surface, sont utilisées dans des applications industrielles comme le Reverse Engineering, les techniques de dentisterie, la construction aéronautique et automobile, la fabrication d'élément d'optique et les systèmes de gestion de qualité.
En collaboration, ou sous contrats avec des industriels, l'institut conçoit et développe des systèmes mécaniques de précision, à savoir des manipulateurs de précision et des machines hautes résolution pour la lithographie, et développe des techniques d'assemblage pour les systèmes optiques et micro mécaniques.
Les développements de projets menés à bien au Fraunhofer IOF incluent les méthodes et équipement pour les mesures et les tests des composants mentionnés, la manufacture de prototypes comme les tests de pré production en série.
En engageant une collaboration avec Fraunhofer IOF, les clients industriels augmentent leur potentiel de fabrication en créent de nouveaux produits pour le marché.
Cet institut est en partie financé par l'état, les projets européens et régionaux. Son effectif permanent est de 80 personnes et compte autant en effectif temporaire dans ses laboratoires et bureaux qui s'étendent sur une surface de 3000 m².

Advisory Committee

The Advisory Committee supports the Fraunhofer Institute as well as the Board of Directors of the Fraunhofer-Gesellschaft and is comprised of the following members:

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Lehrstuhlinhaber für Technische Optik
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Ministerium für Wissenschaft,
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  Dr. Ralf Waldhaeusl

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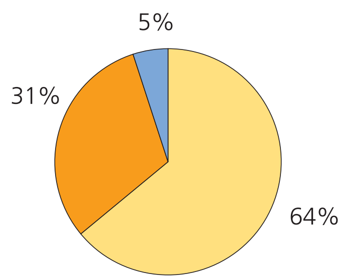
- **Microassembly**
  Dr. Ramona Eberhardt
- **Precision Systems**
  Dipl.-Phys. Stefan Risse
- **Mechanical Simulation and Design**
  Dr. Thomas Peschel

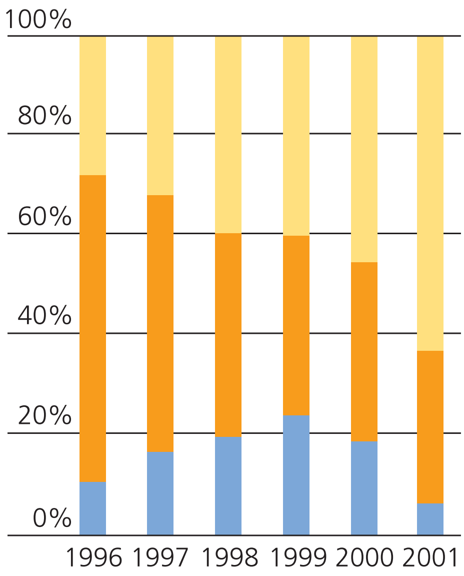
Competences of Fraunhofer IOF

Business fields	Competences	Design and analysis of optical and optomechanical systems	Microoptics technology and systems	Optical shape and surface measurement	Optical coatings technology
Devices and subsystems for optical information technology, laser technology and illumination		●	⬤	•	●
Optical test and measuring methods/optical sensing		●	●	●	•
Modules for mechanical precision systems		⬤			
Optical coatings		●	•	●	⬤
Medical-optical equipment and methods		•		●	•

Budget year 2001

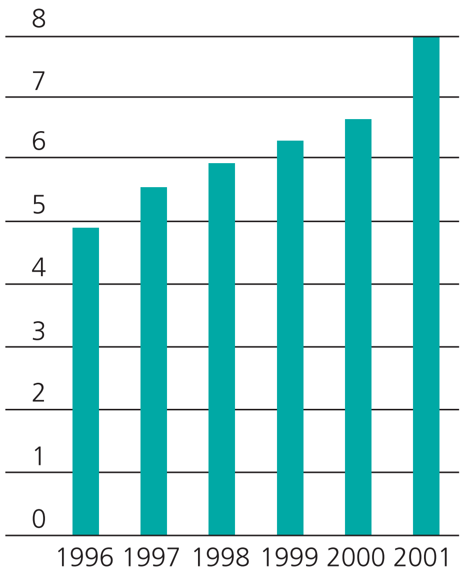


Budget

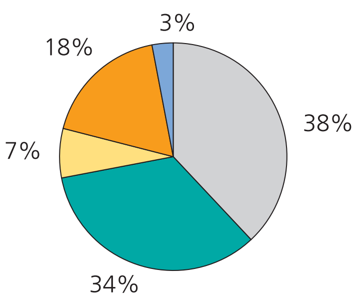


- Contracts (Industry)
- Contracts (Government)
- Federal Funding

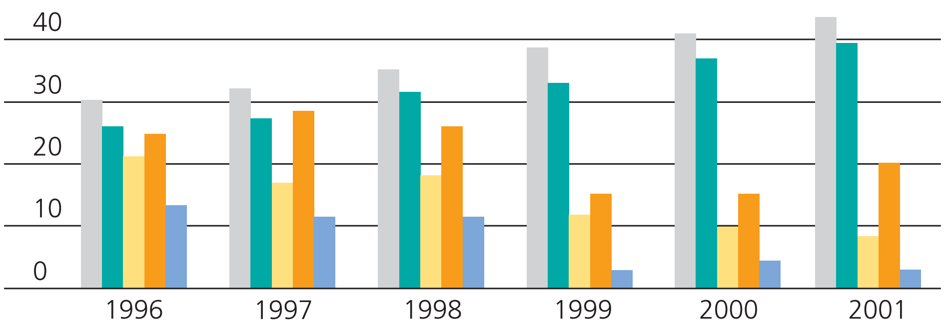
Budget (Mio Euro)



Staff year 2001



Staff (overall employment figures)



- Scientists
- Technicians
- PhD students
- Undergraduate and graduate students
- Temporary contracts

The Fraunhofer-Gesellschaft – Overview

The Fraunhofer-Gesellschaft is the leading organization for institutes of applied research in Europe, undertaking contract research on behalf of industry, the service sector and the government. Commissioned by customers in industry, it provides rapid, economical and immediately applicable solutions to technical and organizational problems. Within the framework of the European Union's technology programs, the Fraunhofer-Gesellschaft is actively involved in industrial consortiums which seek technical solutions to improve the competitiveness of European industry.

The Fraunhofer-Gesellschaft also assumes a major role in strategic research: Commissioned and funded by Federal and *Länder* ministries and governments, the organization undertakes future-oriented research projects which contribute to the development of innovations in spheres of major public concern and in key technologies. Typical research fields include communications, energy, microelectronics, manufacturing, transport and the environment.

The global alignment of industry and research has made international collaboration imperative. Furthermore, affiliate Fraunhofer institutes in Europe, in the USA and in Asia ensure contact to the most important current and future economic markets.

At present, the organization maintains 56 research establishments at locations throughout Germany. A staff of some 11,000 – the majority of whom are qualified scientists and engineers – generate the annual research volume of more than 900 million €. Of this amount, over 800 million € is derived from contract research. Research contracts on behalf of industry and publicly financed research projects generate approximately two thirds of the Fraunhofer-Gesellschaft's contract revenue. One third is contributed by the Federal and Länder governments, as a means of enabling the institutes to work on solutions to problems that are expected to attain economic and social relevance in the next five to ten years.

Fraunhofer scientists specialize in complex research tasks involving a broad spectrum of research fields. When required, several institutes pool their interdisciplinary expertise to develop system solutions.

The Fraunhofer-Gesellschaft was founded in 1949 and is a recognized non-profit organization. Its members include well-known companies and private patrons who contribute to the promotion of its application-oriented policy.

The organization takes its name from Joseph von Fraunhofer (1787–1826), the successful Munich researcher, inventor and entrepreneur.

Selected Results

Fraunhofer IOF research and development activities carried out during 2001 and brought at least to a preliminary stage of completion are presented here. The work undertaken by the various departments at the institute illustrates the competence in cooperating with both private enterprises and multiinterest projects.

Our competence matrix has been adapted to the development of business fields and the concentration of our competences. The qualitative and quantitative extension of the core competence in the design of optical and optomechanical systems, its concentration on microoptics and combination with mechanical precision systems were continued.

The know-how of the Fraunhofer IOF in microoptics is demonstrated by the papers on devices for optical sensing in machine engineering, other applications, and examples on fabrication technologies.
The projects in precision engineering show the competence for developing of the equipment for automatic adjustment and assembly of fiber optical devices and also for semiconductor fabrication equipment.

Progress in 3-D shape measurement could be achieved by application in a few projects, the research capacity had to be increased for this field. Further development of self-calibrating technique and evaluating methods is presented.

In optical coating technology we focused on the development of high performance coatings for short wavelength. With respect to the next generations of photolithography equipment the research activities were extended in the wavelength range from 157 nm to 1 nm. Radiation resistance for Excimer- and Free Electron Laser, new multiplayer coatings for EUV are presented just as new design for coatings of plastics. Measurement technique for coatings in the VUV range are also described.

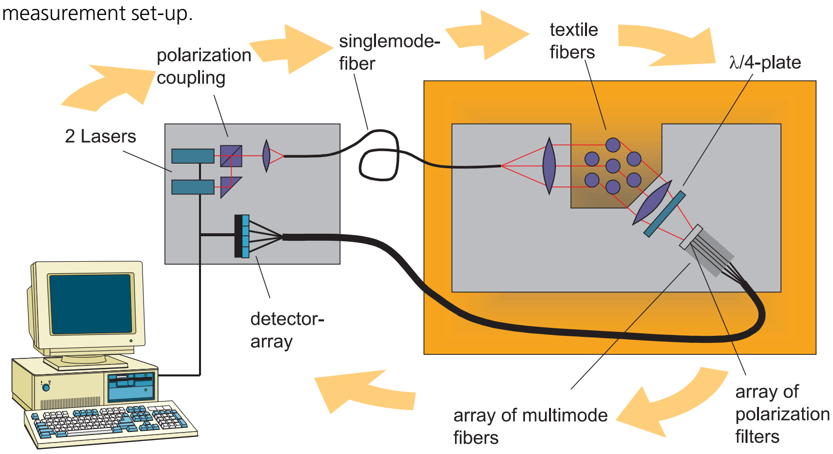
Microoptical sensor for online characterization of textile fibers

U.D. Zeitner, S. Kaufmann*, and R. Rosenberger*
Thüringisches Institut für Textil- und Kunststoff-Forschung e.V.

Introduction

Modern textile industry has an increasing demand on artificial high-performance fibers. A lot of technical applications require precise and constant properties of the filaments which therefore have to be already controlled during the spinning process. This can be done by measuring either mechanical or optical fiber parameters. However, measuring the optical properties is often better suited than measuring the mechanical ones. Using optical methods the measurement speed may be higher and a contactless sensor system is obtained.
In general, there are two parameters giving a representative overview of the fiber properties being the fiber diameter and the optical birefringence. From both parameters the degree of polymer-chain orientation in the fiber and therefore the state of its racking can be estimated. This property is important for the mechanical behavior of the fiber in later applications. Within the framework of the project "Sentex" the IOF developed in cooperation with the Thüringisches Institut für Textil- und Kunststoff-Forschung, different small companies and an Institute of Friedrich-Schiller-University Jena a microoptical sensor for the online measurement of the fiber-parameters mentioned above.

Fig. 1:
Sketch of the measurement set-up.



Realization of the sensor

In order to qualify the sensor for application in a common spinning machine, special demands for the geometrical extension of the detector housing, the measurement speed and the operation temperature and humidity has to be fulfilled. The extension of the available measurement volume in some spinning machines is limited to about 6 mm in direction of the fiber movement.
In the environment of the sensor a temperature up to 80°C and a relative humidity of nearly 100% may occur depending on the particular spinning process. During the online characterization of the fibers up to 8000 meter fiber per minute pass the measurement set-up. In order to realize a measurement in such an environment the microoptical sensor system has been split into one part containing the light sources, detectors, and electronics and a second part for the measurement line containing only microoptical components such as lenses for beam shaping, filters and waveplates. The connection between the two parts is established by single- and multimode optical fibers for illumination and detection, respectively.
The estimation of the birefringence is done by the so called Senarmont-method /1/. For this method the fiber is illuminated with linearly polarized light, tilted by 45° with respect to the fiber axis. The direction of the mechanical stress during the racking of the fiber is along the fiber axis which is therefore identical with the birefringence axis. The light transmitted through the fiber is elliptically polarized because of the different refractive indices for the field components parallel and orthogonal to the fiber axis. A quarter-wave-plate oriented by 45° with respect to the fiber axis transforms the polarization state of the transmitted light into a linear one whose polarization direc-

tion is a measure for the strength of birefringence in the textile fiber. As a result the estimation of birefringence is reduced to a measurement of the orientation of linearly polarized light. However, there is an uncertainty of N × λ (with *N* being an integer number) for the measured birefringence if the path difference for the two orthogonal polarization directions parallel and orthogonal to the textile fiber axis is larger than λ. By using two illumination wavelengths λ_1 and λ_2 being not too different, the range of a reliable birefringence detection can be extended to path differences up to $\lambda_1^2/(\lambda_2-\lambda_1)$.
In order to have a compact detector set-up without moving parts, the polarization direction of the transmitted light is measured with an array of polarization filters lithographically realized as so-called wire-grid polarizers. These filters consist of metallic grids having a grating period smaller than the wavelength of the used light oriented under 3 directions (0°, 60° and 120°) with respect to the axis of the textile fiber. For the present case the grating period is 300 nm and the area of each filter is 300 µm x 300 µm. The filter array is mounted to the facet of an array of multimode fibers which guide the transmitted light to photodiodes. A sketch of the measurement set-up is shown in Figure 1.
Two laser diodes at λ_1= 630 nm and λ_2= 650 nm are coupled into a polarization maintaining single mode fiber and at the fiber output two cylindrical lenses are used for optimal shaping the beam for illumination of the textile fibers. In order to separate the light transmitted through the textile fibers from the light passing by these fibers the optical axis of the polarization detection is arranged under an angle of 45° with respect to the direction of the collimated illumination beam.
A collecting lens directs the light onto the filter array and the multimode fibers. The measurement at the different wavelengths is performed in succession and controlled by computer which also calculates the path difference from the detected signals. Photographs of the detector stage and the measurement plate are shown in Figure 2. The thickness of the plate is 6mm including the cover.
Furthermore, a detection system for the measurement of the fiber diameter based upon a modified spectrum analyzer is implemented into the measurement plate. This system has been developed by the project partner ETA-Optik. From both measurement results, the birefringence and the diameter, the state of racking of the textile fiber can be estimated.
In conclusion the developed sensor system can be easily inserted into common spinning machines for characterization of textile fiber properties during the spinning process. The measurement method gives correct results for the strength of birefringence also if the path difference between orthogonal polarization components is larger than one wavelength. The construction of the system fulfills the tight space requirements in the spinning machines.

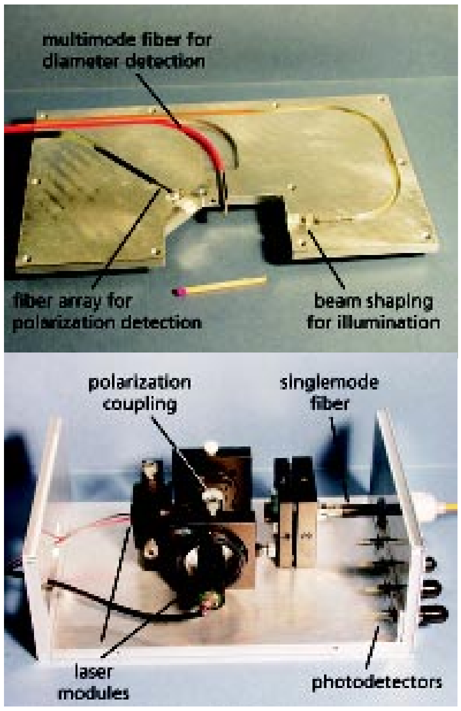


Fig. 2:
Microoptical sensor system with source and detector stage and measurement plate (covers removed, detector stage without electronics).

Acknowledgement

This work was founded under contract 16SV 951/3 by the German Ministry of Education, Science, Research and Technology. We like to thank Dr. Beyer from B + B Gerätetechnik and Dr. Kley from FSU Jena Institut für Angewandte Physik for support during the project.

References

/1/ S. Kaufmann, E.-B. Kley, „Zur Eindeutigkeit und Miniaturisierung des Senarmont-Verfahrens bei online Messungen," DGaO Jahrestagung, Kloster Banz, 21.–24. Mai 1997

Micro optical elements fabricated by RIE proportional transfer

A. Matthes and P. Dannberg

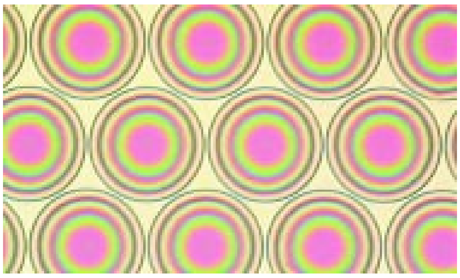


Fig. 1:
Extreme shallow structures (Ø120 µm, sag 1µm).

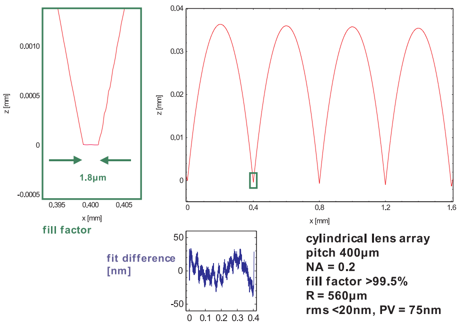


Fig. 2:
Surface profile of refractive cylindrical lens array in photoresist.

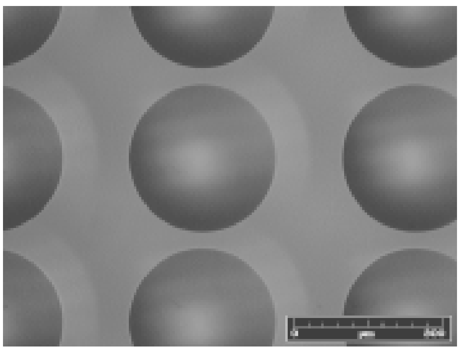


Fig. 3:
Aspheric lenses etched to borosilica glass.

One competence of Fraunhofer IOF is the wafer scale fabrication of micro optical elements. We apply photo-lithography in combination with reflow techniques or laser grey scale lithography for structure generation and UV micro moulding technique for structure replication. The corresponding thin film equipment is established so far for the preparation of optical elements based on polymers. Some applications demand for features exceeding that of polymer optics concerning first of all optical power densities, extended wavelength transparency and mechanical and chemical resistance. In those cases, fabrication of optical elements in appropriate inorganic materials is required.
Supplementing our thin film polymer technology we have realized reactive ion etching (RIE) processes with the objective of proportional transfer of polymer optical elements prepared on wafers of fused silica, borosilica glass and silicon to the corresponding substrate material.

Polymer Technology

The IOF resist technologies for generation of micro optical elements and arrays on a wafer scale are based on commercial thin-film equipment and lithographic processes. High accuracy of the generated profiles is the main focus in the generation of optically functional surfaces in photoresist, as well as good homogeneity across the wafer, good repeatability, low surface roughness and a suitable stabilisation of the structures for the subsequent RIE transfer.
Special features are a broad variety of spherical and cylindrical reflow lenslets including those with arbitrarily small contact angle (Fig 1). The surface roughness of reflow patterns is well below 1nm rms. Spacings between lenslets can be as small as 1.5 µm, independent of the lens dimensions (Fig. 2); the homogeneity of the focal length (or sag) across a 4" area can be below ±1%. Furthermore, the combination of reflow and variable dose writing has been realized resulting in multifunctional optical elements. Structures on top and back side of a wafer can be aligned with an accuracy of ±2 µm. Lateral precision and good homogeneity are the prerequisite for a potential wafer scale integration of subsystems.

RIE proportional transfer

We have focused our efforts mainly to the proportional transfer of polymer masks prepared in reflow technology. The reactive ion etching (RIE) is done in fluorocarbon or SF_6 based plasma chemistries aiming at a selectivity (etching rate ratio of substrate : polymer mask) near 1:1 which is most favourable for proportional transfer. Typical RIE parameters (pressure 2…6 x 10^{-3} mbar, bias voltage about 250…400 volts) are adapted to yield best results concerning profile accuracy and surface quality necessitated by the use for high performance optical systems.
A continuous process control, particular control of selectivity was proved and successfully applied for the purpose of controlling the lens profile even to form aspheric lenses as well as to counteract some detrimental effects caused by the etching process itself.
The RIE process results in flattening of the etched profile in comparison to the primary polymer profile depending on its dimension and a surface etch removal attributable to an almost isotropic etch effect, even though the RIE plasma process is an anisotropic one. This isotropic effect limits fill factors of arrayed optical elements, or the minimum distance between

neighbouring lenses, respectively.
By modelling the transfer process and assuming 100% isotropic etching effect we found best consistence with experimental data. Referring to this we are able to predict the limits of process control in order to adjust a particular profile, its evolution during etching itself and the expected dimension loss.
The following table estimates the limits for conical constants k of etched borosilica lenses depending on numerical apertures NA taking into account only the potential of selectivity control.

NA	0.11	0.12	0.13	0.15	0.19
k	-6	-5	-4	-3	-2

The calculation was done irrespectively of other effects. Especially the stronger influence of the profile flattening for the higher numerical aperture elements with etch depths larger than about 20 µm may extend deviations from requested profiles.

The achieved accuracy of proportional transfer is best illustrated by the following example.
Fig.3 shows aspherical lenses etched into borosilica glass starting with spherical polymer lenses prepared in reflow technology. The profiles before and after etching are shown in Fig.4 revealing also the inevitable loss of diameter during etching. For this particular geometry (NA = 0.11 and lens diameter= 300 µm) we achieved k = -5.6 characterizing also the limit of selectivity control.
Fig. 5 indicates the deviations from the ideal profiles, i.e. from a sphere before etching and from a conical profile after etching. The process obviously reproduces the deviation from the ideal profiles at nearly the same accuracy. The deviation from the ideal profile is 26nm rms inside 97% of the entire diameter of the etched lens.

The surfaces of etched elements were characterized by AFM measurements. We have demonstrated a surface roughness of less than 5 nm for fused silica, borosilica glass and silicon, see for example Fig.6.

Conclusion

The established thin film technology for preparation of polymer optical elements is a reliable base for the subsequent transfer to silicon, fused silica or borosilica glass.
Corresponding RIE processes have been developed for the transfer of reflow structures. They will be extended in the next future to arbitrarily shaped grey scale structures and, eventually, to other mask/substrate material combinations.

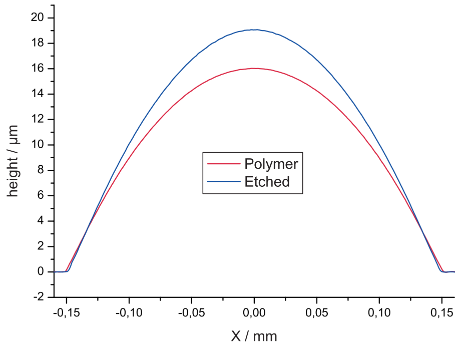


Fig. 4:
Profiles of polymer and etched borosilica lens.

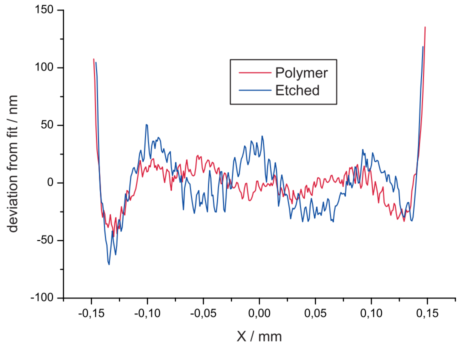


Fig. 5:
Etch transfer of profile, deviation from ideal profiles.

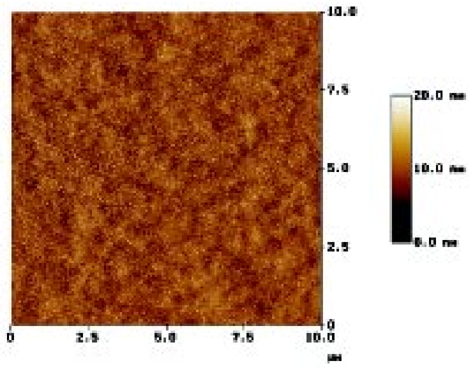


Fig. 6:
AFM measurement of etched borosilica lens surface, rms roughness: 2.7 nm.

Mechanical design of a miniaturized UV-VIS spectrometer for space applications

T. Peschel and C. Damm

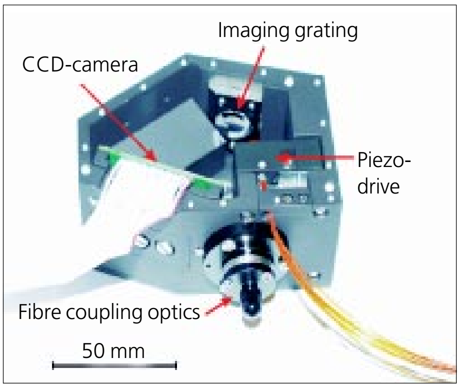


Fig. 1:
View of the spectrometer head with cover plate removed.

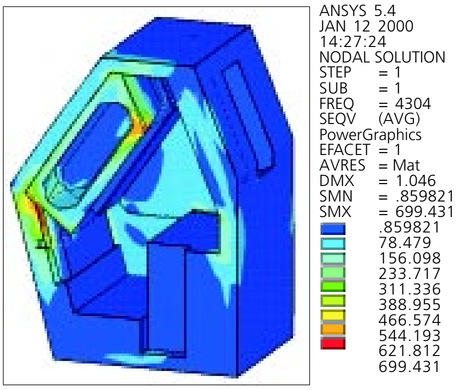


Fig. 2:
Deformation and stress distribution corresponding to the lowest vibration mode of the spectrometer. The cover plate was removed only for the display of results.

Under a contract with the European Space and Technology Center (ESTEC) the Institut für Physikalische Hochtechnologie (IPHT) and the Fraunhofer Insitute für Angewandte Optik und Feinmechanik (IOF) developed a prototype miniaturized UV-VIS spectrometer for space applications (see Figs. 1 and 3).
In the framework of the project the IPHT was in charge of the general layout of the spectrometer optics which relies on their double array architecture /1–5/ and operates as a HADAMARD transform spectrometer. As a subcontractor Carl Zeiss Jena GmbH performed the detailed optical design (together with IPHT) as well as the fabrication of the grating. The optics relies on a holographically structured imaging grating.
The slit mask is driven by a piezoelectric actuator which was fabricated by the company piezosysteme jena GmbH.
The spectrometer uses a commercially available CCD-array as its sensor. The sensor electronics was supplied by the company highRes Ingenieurgesellschaft mbH.
The mechanical design of the spectrometer was performed by IOF. The design is based on a rigid aluminum frame with precision manufactured reference flats, which hold the optical components. The frame is covered by aluminum plates on its bottom and top sides. This symmetric layout allows to realize a nearly homogeneous stress distribution which guarantees a minimum dislocation of the optical elements under both acceleration and thermal loads.
The whole spectrometer head is covered with a Plasmocer® /6/ coating to suppress stray light. Additionally stray light traps, which are integrated into the bottom and top cover plate, suppress the undesired diffraction orders of the grating. In connection with the new coded mask technology of IPHT for the entrance slits this allows to reach a stray light level which is limited only by scattering at the grating itself.
To ensure that the mechanical design provides for the necessary stability of the spectrometer setup during launch and operation of the spacecraft the mechanical and thermal properties were investigated via Finite Element Analysis already in the design phase. For the vibration stability the eigenfrequencies of the housing are of particular importance. Our calculations predicted a lowest frequency of 4.3 kHz which is well above the excitation spectrum during launch (see Fig. 2). Correspondingly no severe resonance frequencies were found in the vibration tests.
The parts of the spectrometer housing were manufactured by milling. Finally the inner contour of the frame of the spectrometer head with its reference flats for the optical parts was finished by wire-eroding.
Before assembly the actual dimensions of all vital parts were measured either on a tactile 3-D measuring machine or optically. With the resulting data optimum positions for adjustment of the optical components were determined.
Alignment of the optical components was performed in two steps. First the slit assembly was adjusted. The following position accuracy (r.m.s. errors) of the slit assembly with respect to the position of the grating could be reached:

- distance 20 µm,
- in-plane position 13 µm, and
- out-of plane position 7 µm.

Finally the CCD was adjusted according to the measured spectral images.

The results of the following tests of optical and mechanical performance agreed completely with the goals of the project.

The achieved optical and mechanical parameters of the spectrometer are summarized in the table 1.
Taking into account the achieved performance parameters our instrument is the smallest high-resolution grating spectrometer available today.

Optical performance	
spectral range	250–675 nm
spectral resolution	1.2 nm (using self-adjustment software by IPHT)
stray light level	about $2.5 \cdot 10^{-5}$
numerical aperture	0.08
interface to multimode fiber	with NA = 0.2
Mechanical parameters	
mass of the spectrometer head	650 g
size of the spectrometer head	300 cm^3
shock, vibration and temperature tests according to Ariane launch loads	passed

Table 1:
Performance parameters of the micro-spectrometer

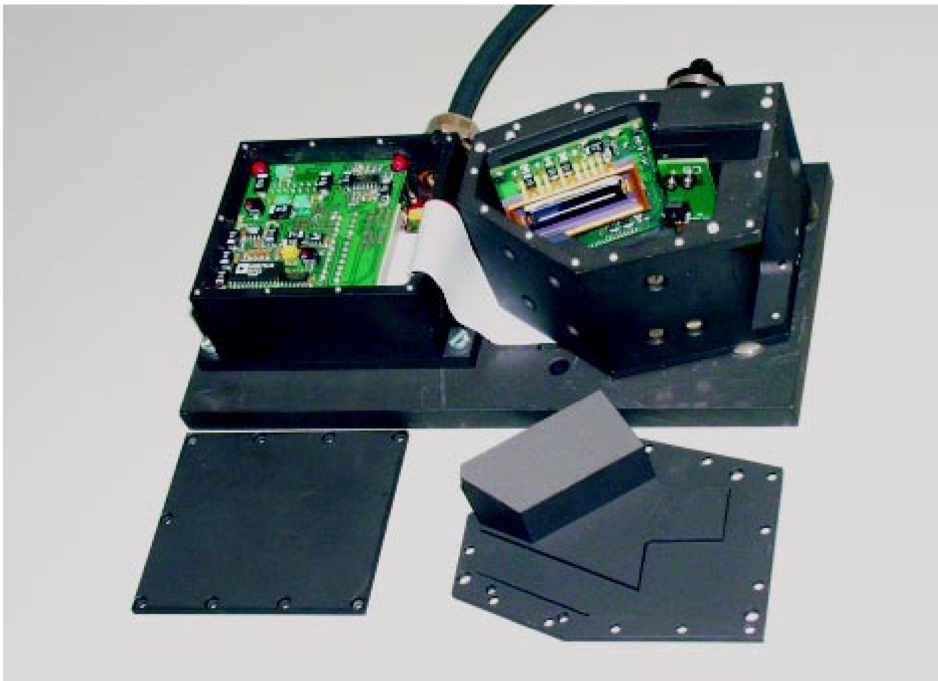


Fig. 3:
View of the complete spectrometer

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Anomalous light propagation and diffraction control in waveguide arrays

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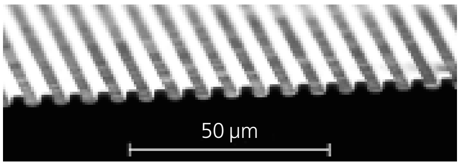

Fig. 1:
Polymer waveguide array of 75 single mode waveguides (before applying the polymer cladding).

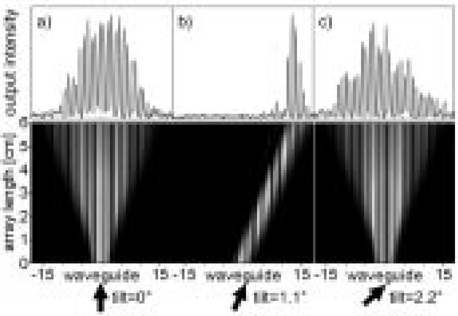

Fig. 2:
Measured output intensity profile and simulated propagation for a Gaussian excitation with several input tilts.

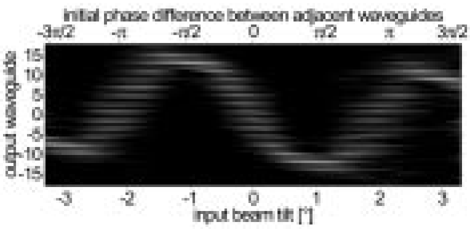

Fig. 3:
Measured output intensity profiles vs. tilt of a Gaussian input beam.

Introduction

Our understanding of light propagation primarily derives from isotropic media. The law of refraction predicts that the tilt of a beam traversing an interface between two media will monotonously grow with the angle of incidence. The law of diffraction predicts beam spreading being completely determined by the ratio of wavelength and width, which is only slightly affected by the refractive index and independent of the tilt. The reason for this behavior is the rotational symmetry of the isotropic medium. If this symmetry gets lost, as e.g. in a stratified medium (Bragg mirror) or a discrete system (array of waveguides), these canonical laws of refraction and diffraction cease to hold. The mathematical background is the relation between the transverse (k) and the longitudinal wavenumber component (b) of the wave vector, which constitutes the diffraction relation analogously to the dispersion relation in the temporal domain. In two-dimensional isotropic media we have $\beta = \sqrt{n^2 - \kappa^2}$ whereas in the general case this is a more complex function $\beta = f(\kappa)$. We demonstrated anomalies in light refraction and diffraction in evanescently coupled waveguide arrays ('discrete' refraction and diffraction) /1-3/.

Experiments

The experiments were performed on homogeneous arrays of 75 waveguides in an inorganic-organic polymer (n_{co}=1.554) on thermally oxidized silicon wafers (n_{sub}=1.457) with polymer cladding (n_{cl}=1.550) (Fig. 1). The 6 cm long samples were fabricated by UV-lithography on 4" wafers. Each waveguide has a cross-section of 3.5 x 3.5 µm^2 and provided low loss single mode waveguiding (< 0.5 dB/cm) at λ = 633 nm. The uniform separation of adjacent guides was 8.5 µm to achieve efficient evanescent coupling. A HeNe laser beam was shaped with respect to width and tilt using a telescope and coupled into the array via the entrance-facet with a microscope objective. The light emitted from the end-facet is detected by a camera. Because light propagation along the array cannot be monitored, it is visualized by numerical simulations instead.

In Fig. 2 the most spectacular consequences of anomalous refraction and diffraction are displayed. In Figs. 2a and 2c measurements and modeling show that, like in an isotropic medium, diffraction of a Gaussian input beam compares for two different input angles. But refraction is anomalous, i.e., the 2.2° tilted beam exits the array at the same location as the untilted beam. On the contrary, Fig. 2 b is an example for normal refraction but anomalous diffraction because the beam, which is tilted by 1.1°, crosses the array diffractionless.

To systematically study these anomalies we continuously varied the angle of incidence of the beam. This was achieved by shifting the laser beam off-axis in front of the in-coupling microscope objective, resulting in a stationary focus with a tilt proportional to the off-axis translation. We monitored the field at the output facet, the shift of which is proportional to the angle of propagation inside the array. For an isotropic system this shift would monotonously grow with the tilt and the beam width at the exit face would be invariant for changing tilt. In fact, for small angles the transverse motion of the field in the array was found to be proportional to the initial tilt. But for growing angles this shift saturated and even reduced resulting in an oscillatory dependence (see Fig. 3). Evidently, two features of light propagation can be recognized, there is a maximum angle of propagation that cannot be exceeded and the width (strength of diffraction) varies with the input angle.

Theory

The theoretical analysis is based on a coupled mode theory. This means that the incident field is mapped onto a finite number of mode amplitudes of the individual guides. Therefore, phase differences between adjacent guides of multiples of 2π will have no effect on the field evolution. Apart from a reduced incoupling efficiency, the response of the array on initial tilts must be periodic as observed in the experiment. Furthermore, the output field remains at the initial waveguide if a phase difference of integer multiples of π between adjacent waveguides is reached. For the corresponding initial beam tilt the transverse motion of the field in the array is steadily prevented by Bragg reflection at the periodic array structure.
The dependence of the beams transverse motion and its diffractive spreading on the beams input tilt reflects the anomalies in refraction and diffraction in an array. The most striking features are an upper limit of the transverse motion and diffractionless propagation. Evaluating the experimental results we can show these features quantitatively, see Fig. 4. In contrast to isotropic materials, diffractive spreading depends on the angle of incidence. Note that for a tilt of about 1.1°, corresponding to a phase difference of $\pi/2$ between adjacent guides, the beam retains its original shape, i.e., diffraction is arrested. Moreover, the angle of diffractionless propagation is that of the maximum transverse shift. One can show that the sign of the diffraction will change if the tilt of the exciting beam exceeds the angle of diffractionless propagation. But this has no effect on the width of the beam and is just as if the beam would travel backwards in space. This is reflected in the experiment by the similar output fields for an initial phase difference of zero and

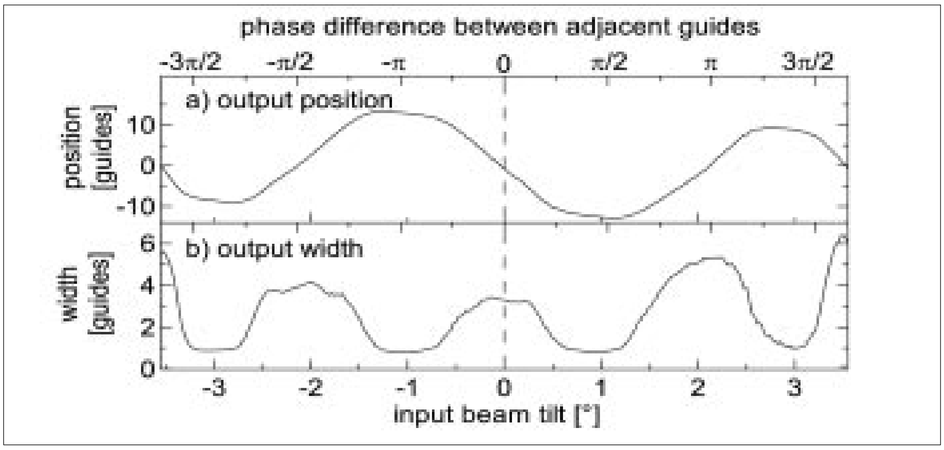

Fig. 4:
Output position (a) and output width (b) determined from the measurements in Fig. 3.

between adjacent guides (see Fig. 2 a, b). Therefore, a tilted array can be used as a simple imaging element.
In conclusion, we have studied the propagation of beams in homogenous waveguide arrays. It turned out that refraction and diffraction exhibit strong anomalies as they depend periodically on the initial beam tilt. In contrast to isotropic systems we found that the transverse energy transport cannot exceed a certain maximum velocity and that diffractive spreading depends on the direction of propagation, i.e., by varying the angle of incidence size and sign of diffraction can be controlled and it can even be arrested. For particular initial tilts the array can undo beam spreading. Therefore, a tilted waveguide array can form a simple imaging system.
The authors gratefully acknowledge a grant of the Deutsche Forschungsgemeinschaft (SFB 196).

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Adjustment robot for fibre optics assemblies

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B. Maisenbacher**, D. Barnhart**, and B. Nebendahl**
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Fig. 1:
Impulse drive

In cooperation with Agilent Technologies, a manufacturer for communications and life science equipment, Fraunhofer IOF developed a robot for the adjustment of a mono-mode fibre assembly. The major tasks of this project were the development of a fully automated adjustment technology for a fibre optics assembly with minimal attenuation, the visualisation of the robot's operating states, high process stability and certification of the technology for CE-conformity.

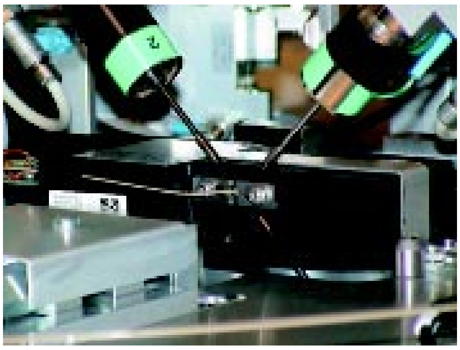

Fig. 2:
Fine adjustment with impulse drive

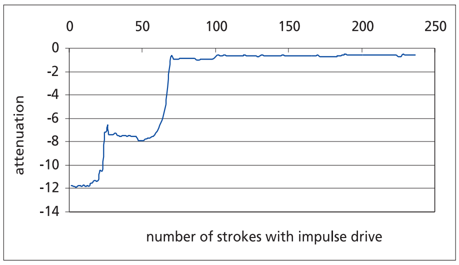

Fig. 3:
Minimizing of attenuation

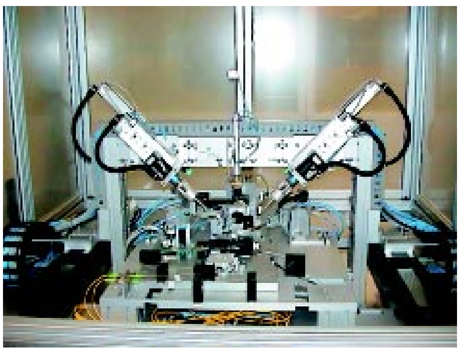

Fig. 4:
Partial view of adjustment robot

Technological solution

The main idea of the robot is the adjustment with the help of an impulse drive which was developed by Fraunhofer IOF: The movable parts of electromagnets transfer measured strokes either directly to the part that needs to be adjusted or indirectly on its mounting. The strokes (intensity, number and direction) are controlled by a measurement system and a software algorithm.

With the help of the electromagnets the fibre flanges are moved in the x- and y-direction. The dynamics of the adjustment system are designed to have large increments for coarse pre-adjustment and sub-micron increments for fine adjustment movements. Furthermore the software algorithm allows the consideration of different pre-stressing and friction coefficients between the adjusted part and its mounting. With the components already being fixed before the adjustment takes place they meet the strong demands for telecommunication devices at shock and vibration.

The pre-adjustment of the fibre flanges and the coarse adjustment of the whole optical system is measured by the position of a transmitted laser beam in front of an infrared camera. Image processing algorithms detect the position and the size of the laser spots and control the adjustment towards the target parameters.

The fine adjustment is exclusively controlled by measuring the attenuation of the total system and minimizing it by adjustment. This process takes only few seconds.

Results

An adjustment robot was developed that automatically adjusts a fibre optic assembly completely. The user of the robot only needs to insert the pre-assembled optical device at the beginning and take it out at the end. Further assembly steps (e.g. an additionally fixation of the adjusted components) are not necessary.

By the usage of a deterministic adjustment procedure the entire adjustment including various measurements takes only a few minutes. The achieved adjustment accuracy for the fibre optical assembly is in a low micron range for the beam axis and in a submicron range perpendicular to it.

Precise adjustment of mechanical and optical components by linear stroke actuators

C. Siebenhaar, A. Gebhardt, M. Thaut and V. Guyenot

Introduction

The experience that is easier to precisely change the position of an object by using a slight tapping instead of a constant pushing force is applied daily in the realm of manufacturing and optics. Traditional, the positioning of mechanical and optical objects (e.g. work pieces, components, lenses) is activated manually by hammer. Stability and success of such an adjustment process depends highly on the skills of the operator. Nevertheless, misalignments resulting from the subsequent fixation process are inevitable. However, in most cases objective position adjustments need to be made systematically and cost-effectively.

Alternative adjustment method

At the Fraunhofer Institute in Jena, Germany, the manual position adjustment was developed further and replaced by providing an effective and automated adjustment method applied in precision engineering and micro-optical applications. The movable parts of electro-magnets and electro-dynamic actuators transfer measured strokes (momentum) directly to the component which needs adjustment or indirectly on its mounting. The transfer of momentum (intensity, number and direction of strokes) is in feedback control by a computer and a measurement device /1/. Major advantages of the alternative adjustment method are:

– In contrast to conventional methods, this approach immobilizes the components with a pre-stressing force before the adjustment process starts.
– Furthermore, the equipment expenditure are reduced to cost-effective guides, clamps, frames and other adjusting device.
– After the adjustment operation the linear stroke actuators can be used for the next adjustment task.

The design of the pushing magnet is shown in Fig. 1.
In the framework of the joint DFG (German Research Society) project with the University of Stuttgart a linear stroke actuator, as shown in Fig. 2, has been developed and built /2/.

Theoretical and experimental investigations

The theoretical investigations focus on the calculation of motion behavior of such pushed components under consideration of pre-stressing forces and friction /1/. A model of motion was developed utilizing classical collision theories based on the law for rigid bodies. The derived equations of motion for our model takes static and sliding friction forces in place of clamping into account. The conducted experiments aim for an explanation in friction and impact behavior for different specimen. The experimental results confirm the capability of the hypothetical model of motion and the correctness of simplification assumptions made, as shown in Fig. 3. Hence, the amount of motion of fixed (pre-stressed) objects after transfer of momentum can be calculated in good approximation to performed experiments. Such derived equations, characteristic curves and practical experience are be used to enhance algorithms for the automated and fast adjustment of components. Based on theoretical and experimental results, constructive guidelines and parameters can be proposed for usage in alternative adjustment methods.

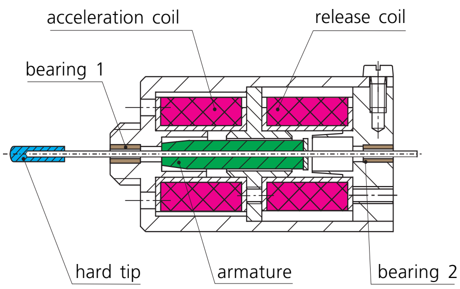

Fig. 1:
Setup of the electro-magnet /1/.

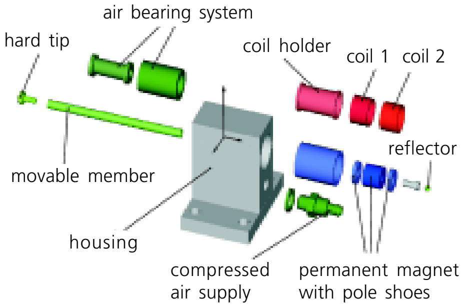

Fig. 2:
Exploded view of the electro-dynamic actuator with air bearing system /1/.

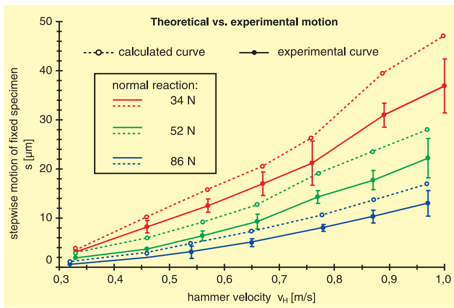

Fig. 3:
Comparison of the theoretical and experimental motion /1/.
pairing: stainless steel
mass: m_H= 4,5 g, m_S= 40 g
friction: μ_{stat}= 0,25, μ_{kin}= 0,18

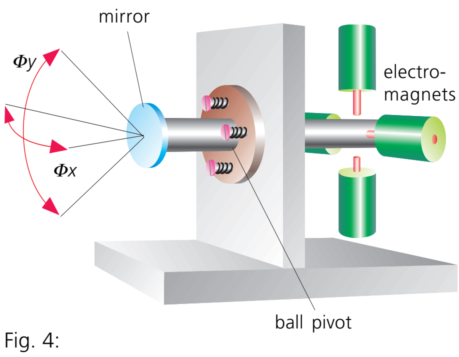

Fig. 4:
Mirror adjuster with four electro-magnets.

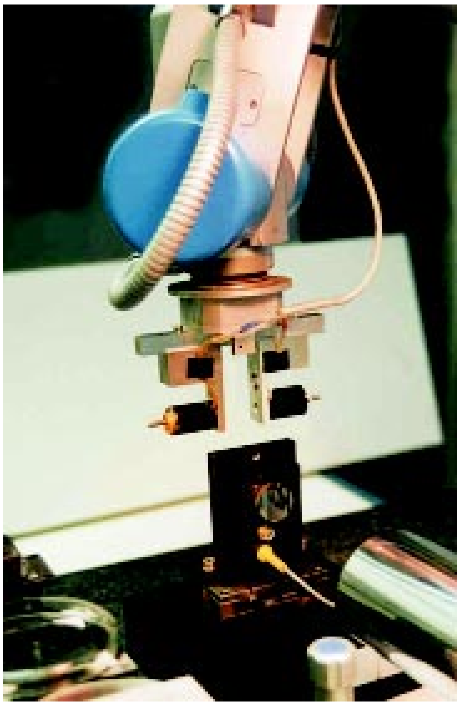

Fig. 5:
Two actuators attached on the endeffector of robot in operation /1/.

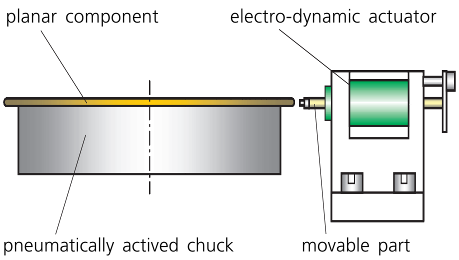

Fig. 6:
X, Y, Z-aligning of planar components.

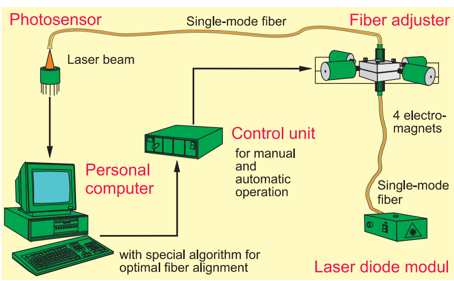

Fig. 7:
Schematic illustration for a fiber optic adjustment /1/.

Applications

This method enables linear and angular adjustment of mirrors, lenses, prisms, fibers and other components in operation.
Various prototypes for optical and micro-optical applications have been investigated and optimized:
The setup of a demonstrator for pitching and yawing of a mounted mirror by four electro-magnets is shown in Fig. 4. Positioning accuracies better than 1.0 arc sec can be achieved in wide range of adjustment.
An interesting and useful application is the adjustment of components using an assembly robot. Two pushing magnets attached on the endeffector enable the exact aligning of a mounted mirror, as shown in Fig. 5. Robots with small positioning accuracy can be used for such positioning task.
In a further application four electro-dynamic actuators make an exact positioning of planar component possible whereas the components are immobilized by the pneumatically activated chuck (shown in Fig. 6). The planar component is exactly aligned to an optical marking in the x, y and z direction using an image processing system /2/.
In another case, a prototype for an automated adjustment of glass fibers in the sub-micrometer range was developed. Four electro-magnets are able to adjust fiber optics by first aligning the fibers to each other. Intensity, number and direction of strokes are controlled by an algorithm and a sensor testing decrease or increase of insertion loss. The complete adjustment process takes only several seconds. A schematic arrangement for the performance of coupling of single-mode fiber is shown in Fig. 7.
An exceptional application for precise aligning of components being in motion is a CNC-lathe with a centering device /3/. The special purpose machine was developed in collaboration with Jenoptik AG. The production process splits into 3 steps. In first step optical lenses are cemented in their housings. The second step involves correction of the centering errors between optical and mechanical axis by two pushing magnets. The final step is turning the cylindrical and plane surfaces of the housing by a conventional precision turning operation. The benefit: Centered and turned lenses can be put in to a cylindrical and finely ground and polished guide tube (barrel) with no additional alignment.

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Precision chucks for future lithography

G. Kalkowski, S. Risse, G. Harnisch, C. Damm, T. Peschel and V. Guyenot

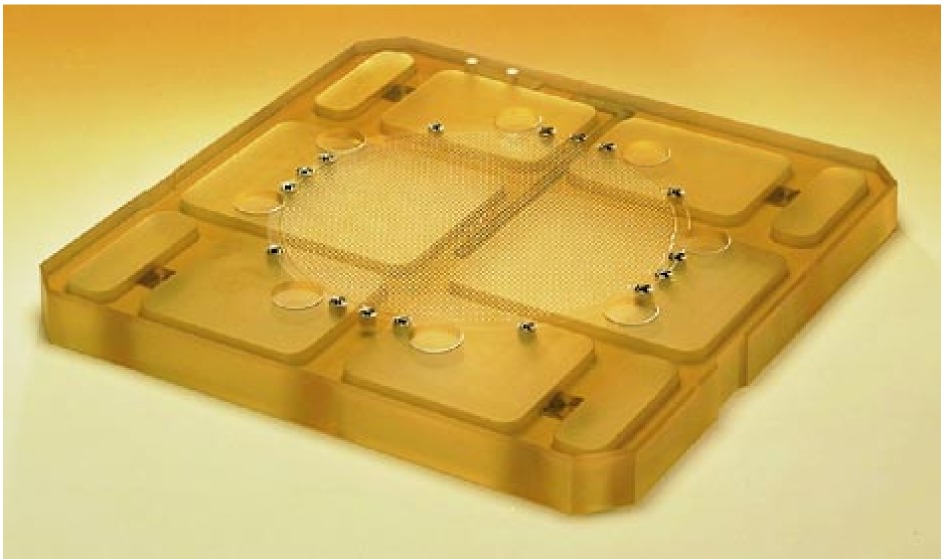
Motivation

In modern electron-beam lithography and -even more important- upcoming next generation EUV-lithography, a very high patterning accuracy (better 30 nm) is desired. This imposes considerable demands on wafer flatness and positioning stability as well as the setup used for clamping the wafer during lithographic exposure. At ambient conditions, fixture of a wafer in the exposure unit is done with a vacuum chuck, which provides a reduced air pressure on the backside of the wafer similar to gripping tools used in picking and placing. This ensures flat adherence and avoids bending or scratches as is quite common with mechanical clamps. Inside vacuum, electrostatic chucking has emerged as a means to obtain closely related results. Through the generation of an electric field between wafer and support, an attractive force is exerted on the wafer. The force is distributed homogenously over the surface, can be switched on/off and adjusted electrically. It provides flat wafer adherence to the support as well as good thermal contact. Development at the IOF comprises chucks based on both working principles -vacuum and electrostatic- and typically combines high precision with athermal design to achieve outstanding lithographic results.

Vacuum Chucks

For holding and smoothing of wafers under ambient conditions, vacuum-chucks are required.
Fig. 1 shows a recently developed 8 inch wafer-chuck at IOF. The surface is implemented with a uniform pin pattern to support the wafer on the chuck evenly with great reliability and provide a flat surface without bending or other deformation from residual particles or dust on the wafer surface. The pin pitch is 3 mm and the pin diameter is 0.8 mm. At the chuck-edge a ring-seal has been structured carefully to omit vacuum leakage. By this seal, the low pressure region below the wafer surface is separated in a controlled way from the ambient pressure above the wafer and around the chuck. The typical vacuum pressure is about 200 mbar lower than ambient pressure.
The clamping process leads to a flattening of the wafer and a defined contact distribution between backside of wafer and pins. The local flatness in a 25 mm square field is better than 0.25 µm and the global flatness of the pin surface with the wafer chucked is better than 2 µm at 8 inch diameter and 4 µm at 12 inch diameter, respectively. The chuck is made of glass ceramics. This kind of material provides high form stability, minimal thermal expansion and high specific stiffness. To reduce total mass, a light-weight structuring on the back side of the chuck has been realized. The design of the light-weight structure was tested by FEM simulation. The whole chuck design has been optimized according to the manufacturing technologies involved, the specific glass ceramic material and a very high stability of the unit.

Fig. 1:
Vacuum chuck (8 inch). Courtesy of Leica Microsystems (Wetzlar).



Electrostatic Chucks

The basic design of an electrostatic chuck closely resembles that of a parallel plate capacitor, with the wafer being used as one of the plates. The second is a metal electrode incorporated into an insulating substrate that supports the wafer from below. By applying a voltage U between the two plates, which are typically separated by a dielectric film of thickness d of several 100 µm, the wafer is attracted to the chuck with a

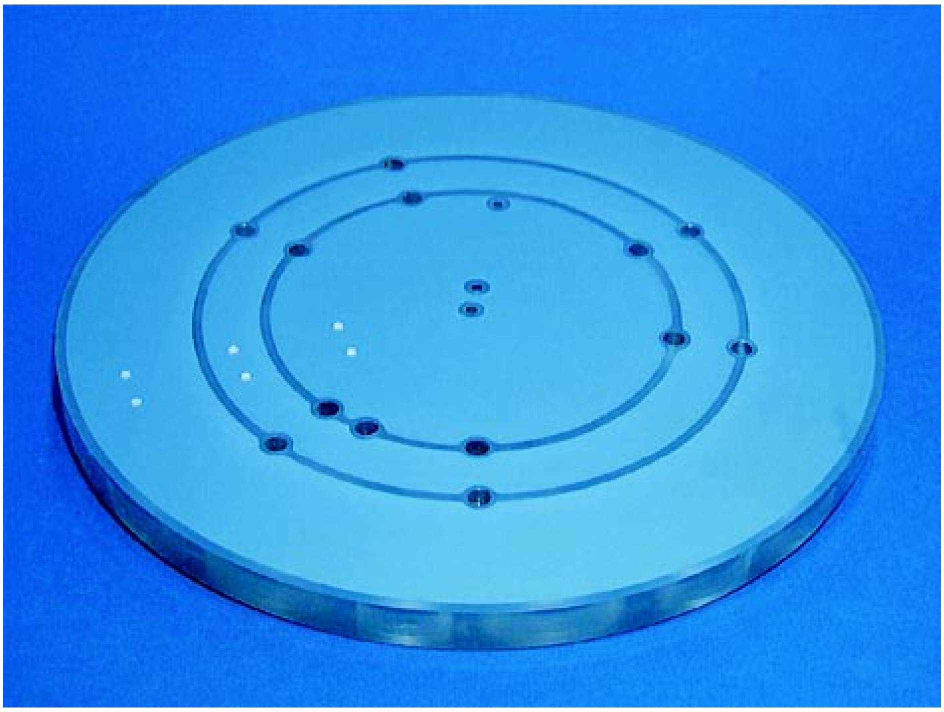


Fig. 2:
Electrostatic chuck (12 inch).

force proportional to $(U/d)^2$. Fig. 2 shows a high precision 12 inch diameter electrostatic chuck made from glass ceramics.
Planarity of chucking surface is about 2 µm and chuck thickness deviations are even less. The chuck electrode can be clearly seen through the transparent dielectric and has been segmented into rings of 6, 8 and 12 inch diameter, to precisely adapt to these wafer sizes. Electrostatic forces were measured in vacuum with smaller test chucks of equivalent design.
Fig. 3 shows the corresponding results (force normalized to chuck area, e.g. pressure) as obtained for different voltages. The pressure variation clearly reflects the $(U/d)^2$ dependency. Note the relatively high pressure values, which apparently are similar to those of vacuum chucks and due to Johnsen-Rahbek behavior of the glass-ceramic dielectric /1, 2/.
Currently, 12 inch chucks which integrated wafer-lift mechanisms for use in Ultra-High-Vacuum are under development.

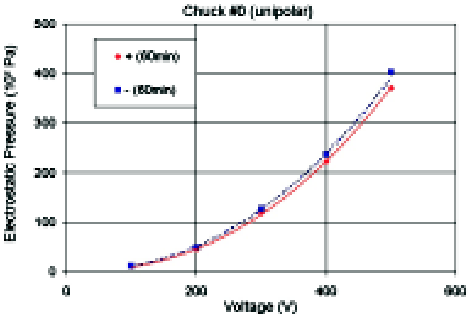


Fig. 3:
Force versus voltage.

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Optical 3-D scanning of extraoral defects using "kolibri-mobile"

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Introduction

Up to now to manufacture prostheses, respiratory masks and extraoral radiation applicators a mold of the part of the human body (in orthodontics and plastic surgery that means the face) have to be done using conventional molding materials such as silicones or alginates. Depending on the material, the molding method and the positioning of the patient, displacement of the soft tissues can thereby occur causing in a subsequent splitting of the edges (marginal gap) of the prostheses /1/. Furthermore, this procedure is really strenuous for the patient. Other technologies are oriented to CT or MRT data, whereby the patient undergoes considerable exposure to radiation. To overcome these problems an optical 3-D scanning technology was developed by the IOF to measure the face of the patient, generating a CAD-model and transfer the data to a rapid-prototyping system for the production of the facial prostheses (epithesis).

The 3-D scanning system – "kolibri-mobile"

For the use of 3-D scanning systems in medical applications like 3-D digitalization of a human face (or other parts of the human body) the scanning system has to fulfil some demands:

- the face have to be viewed from different directions simultaneously;
- the measurement have to be taken within some seconds;
- the system has to be mobile and simple in its use.

At the IOF a concept of 3-D measurement using structured-light illumination with a digital-light projection unit (DMD) has been developed in the years before having the ability to obtain a multi-view within a selfcalibrating measurement procedure, whereas the necessary merging of the single views takes place fully automatically /2/. In the basic measurement procedure the object have to be illuminated by two grating sequences rotated by 90° from different directions. The observing cameras capture these fringe pictures simultaneously resulting in at least 4 phase values for each pixel of the camera. Using these phase values, the 3-D coordinates as well as all of the orientation parameters are calculated. These measurement strategy was the basis of a family of 3-D measurement systems, named "kolibri", successfully applied in industry before /3/. As mentioned above, in some applications, such as human body surface measurement, data evaluation speed up to the whole 3-D image is the crucial point. To realize this we developed on the basis of the explained measurement strategy a mobile and high-speed measurement system, named "kolibri-mobile", see Fig. 1. Here the object is illuminated from different directions via a network of fixed mirrors and simultaneously observed from different directions. The switching of the projection direction is done by a central rotating mirror. The position and number of the mirrors and cameras can be chosen free, adapting the system to the application of interest. In the case to measure a human face an optimum number of cameras is 4 and the number of projection directions is 5, whereby the directions are more chosen from beneath to measure the chin, see Fig. 2.

The following parameters have been achieved with the system:

- measurement field: ∅ 400 mm
- data capturing time (with 4 cameras): < 20 s
- data evaluation time including self-calibration up to the complete 3-D image: < 20 s
- accuracy < 100 µm.

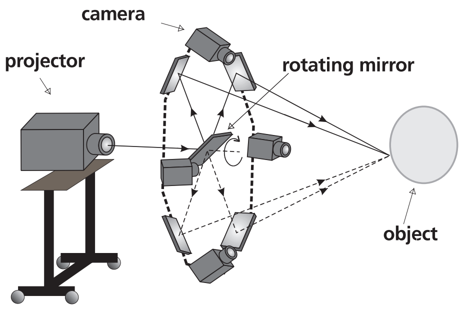

Fig.1:
Schematic sketch of the measurement set-up – "kolibri-mobile".

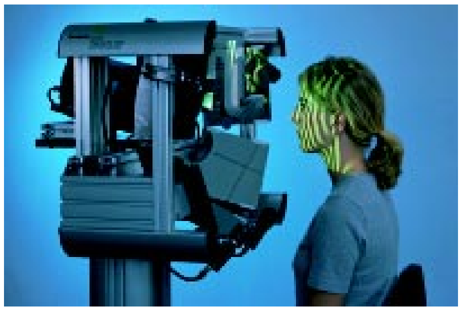

Fig. 2:
Photos of the self-calibrating measurement system – "kolibri-mobile".

The treatment of a patient – epithesis production

The treatment of a patient, start with the 3-D scanning of the face giving an extensive 3-D point cloud. On the basis of the point cloud an STL-model of the face is generated, see Fig. 4. For this a huge number of software-packages exists, like metris, geomagic, surfacer, to name a few. Here the SURFACER V 10.5 has been used. To obtain the volume data of the epithesis the healthy part of the face is mirrored to the ill part. The difference between both give the 3-D volume model of the necessary epithesis. On the basis of the obtained volume-model the rapid prototyping process for the production of the model of the epithesis is started. Here the model is generated by the 3-D printer "ThermoJet" (company 3-D systems, Darmstadt), whereby a polymer of the type ThermoJet 88 has been used. These model can then be tried at the patient. If it fit very well a prosthetic dentist or dental technician makes the final version out of the prosthetic material.

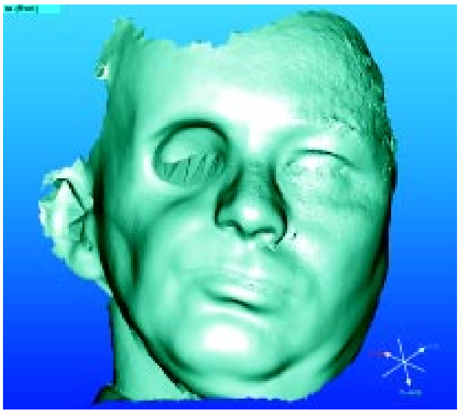

Fig. 4:
STL-file of the face of the patient.

Summary

The use of optical 3-D scanning technique in combination with a rapid prototyping process in orthodontics and plastic surgery has several advantages. For example, displacement of the soft tissues caused by the mold as well as radiation exposure are avoided. The psychological stress caused by the previously techniques used is likewise eliminated. The new process also reduces manufacturing time. Furthermore, the new 3-D scanning system "kolibri-mobile" can by used in different fields of application, like 3-D inspection in the production line, for examples.

Acknowledgements

The development of the scanning system was funded under contract B 609-99033 by the Thüringer Ministerium für Wissenschaft, Forschung und Kultur (TMWFK). We like to thank R.Geller from IVB GmbH Jena and OA Dr. Kopp from the Klinikum of the Friedrich-Schiller-University Jena for support and fruitful discussions during the project.

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High speed 3-D digitizer for CAD-CAM in industrial and dental applications

P. Kühmstedt, S. Riehemann, J. Gerber, and G. Notni

Introduction

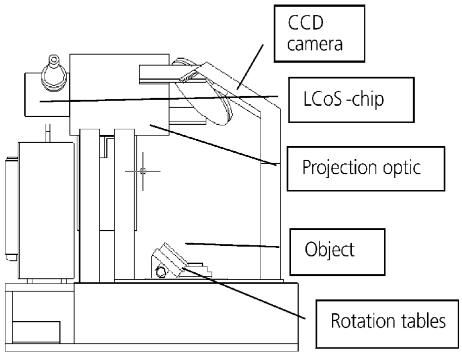
The use of optical 3-D measurement techniques in industry is strongly increasing in a variety of applications, such as quality control, rapid prototyping and in dentistry for production of crowns, bridges and inlays.
Starting from previous developments we employed the principle of uniform scale representation and full hemisphere measurement for 3-D data acquisition recording /1, 2/ and developed a concept for high speed and high resolution measurement.
For this purpose we developed a new optical, mechanical and electronic design of the 3-D digitizer while introducing / adapting high end components like:
– High resolution digital CCD-camera;
– Pixel addressing LCoS projection chip;
– Mechanical system for object handling.

3-D digitizer – system set-up for high speed fringe projection

Our measurement based on the fringe projection technique in a special kind. Its principle is the following one /1, 2/: The measurement is characterized by the exclusive use of phase-measurement values for coordinate calculation. At least three linearly independent phase-measurement values are needed for each object point to calculate the coordinates of this point. To obtain the phase-measurement values, the object under test is successively illuminated by a periodic grating structure (applying Gray-code in conjunction with four 90 degs phase-shifts) from at least three different directions using a telecentric projection system. A CCD camera records the intensity distribution of the fringes intersected by the object. The sample and the CCD camera are both mounted on a large rotation table turning both of them with respect to the fringe projector. The rotation axis has a constant angle with respect to the projection direction. By rotating the object and the camera simultaneously, we can adjust the projection direction.
The system was expanded by including a second rotation axis, that rotates the object with respect to the camera. This second rotation axis is tilted by 40 degs with respect to the first rotation axis. By this way, the object can be view from different viewing directions. Altogether, a whole-body 3-D measurement of the object is possible through using different projection and viewing angles. The pictures in Fig. 1 shows the set-up of the system.

New system components

The main task of work was the selection and integration of new components and algorithm into our system. The high speed fringe projection system is realized by using a non-mechanical projection technique basing upon a pixel addressing reflecting LCoS (Liquid Crystal on Silicon) chip. LCoS and DMD projection elements are novel and effective units for digital fringe projection /3/. They are characterized by the following advantages:
– high resolution,
– short response time for new picture (fringe pattern) generation,
– high contrast,
– simple digital electronic controlling via VGA-signal from the PC.



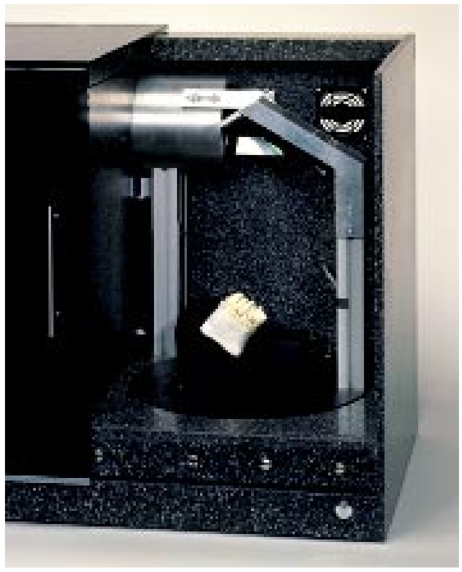


Fig. 1:
(Schematic picture + photo) 3-D digitizer HSDIG.

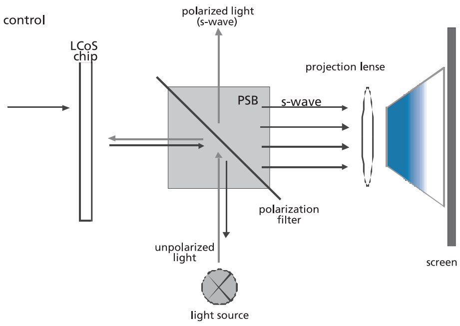


Fig. 2:
Principle of LCoS.

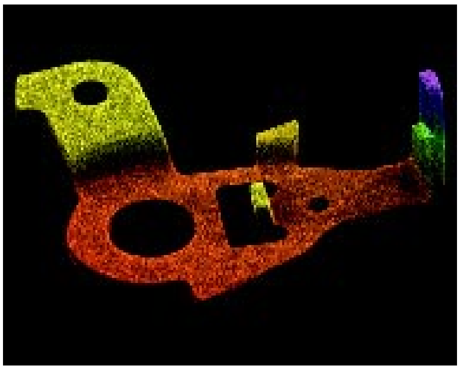


Fig. 3:
Point cloud of a metallic probe, colour indicate height.

The pixels of a LCoS-chip are electronically controlled by the PC and change the polarisation of the incoming light (see Fig. 2). Each Pixel can be addressed separately. Hence, we are able to generate well known Gray-code and phase shift fringe projection technique for phase measurement. Furthermore, a high-resolution digital camera is used as image capturing system. The advantages are:

– Digital data transfer without additional noise from the cables,
– External shutter control for easy adjustment of the light intensity,
– Increase of the point density.

The shutter control offers the possibility to adjust the exposure time to the requirements of different surfaces simply by changing the illumination time directly via the PC without mechanical action in the system (aperture changing). In conclusion, the realized system is characterized by the following parameters:

Parameter of LCoS-Chips:		
	min	max
pixel size	7 µm	20 µm
Pixel number	800 x 600	2048 x 2048
Contrast	70:1/200:1	1000:1
chip size	0,7"	1,5"

Tab. 1:
Parameter of LCoS-chips.

Measurement time	30 sec .. 4 min
Number of views	8 .. 16
Number of points	typical 3.000.000 maximum 16.000.000
Measuring field	∅ 90 mm height 25 mm
Typical accuracy (σ)	< 16 µm

Tab. 2:
Parameter of the digitizing system.

Applications

The system is designed for use in industry and dental labs. For industrial applications the shape measurement of highly complex objects is possible and a CAD-compare process can be realized. Some results are shown in Fig. 3, 4.
Furthermore, in dental application the task is to realize measurements of single tooth as well as the full tooth arc, see Fig. 5, /4/. The measured point cloud is used as an input for an optimised CAD / CAM process for the production of crowns, bridges and caps using different kind of materials like titanium or ceramic (aluminium oxide or zircon oxide) /5/.

Conclusions

The developed high-speed digitizer highly increases the working efficiency of 3-D scanning. The data quality is enhanced by an intelligent consistence check and adapted to the request of dental works. It is straightforward to use the digitizing system in different technical applications, like non-destructive evaluation, quality control or CAD-compare. The concept for high speed and high resolution measurement for industrial and dental purposes is a new step in using the optical 3-D measurement principle in real applications.

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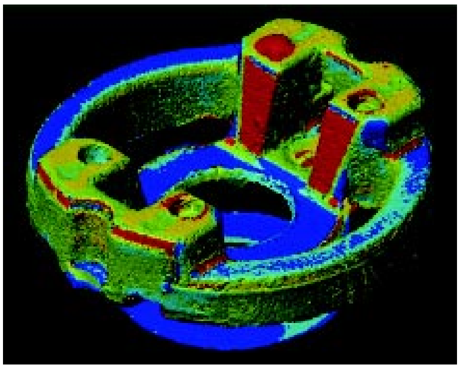
/5/ www.hintel.com



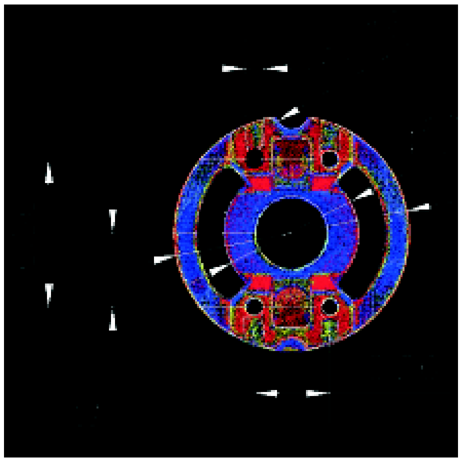


Fig. 4:
3-D-CAD-comparison of a micromechanic part object size: 8 mm, colour indicate deviation

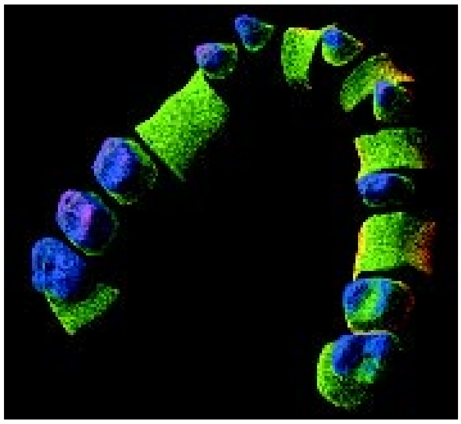


Fig. 5:
Point-cloud of a complete tooth – arc.

Application of microdisplays in optical metrology

S. Riehemann, G. Notni, P. Kühmstedt, and M. Palme

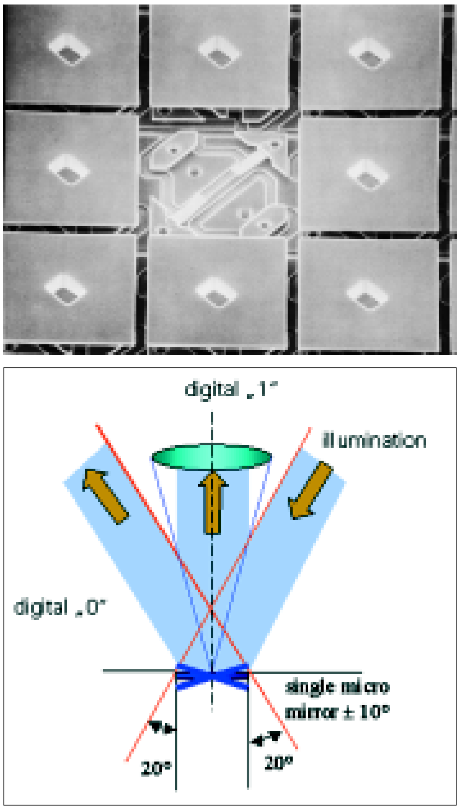


Fig. 1:
Digital Micro-Mirror Display (DMD), microscopic photo of the micromirrors (mirror size 16*16 μm², picture provided by Texas Instruments) and principle of the optical setup.

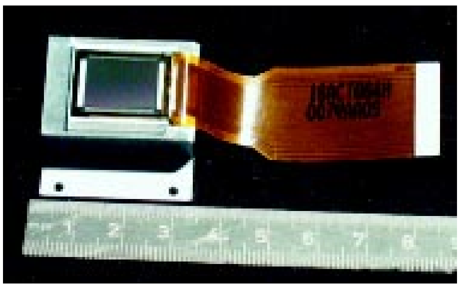
Principle and Potential

For display purposes, digital projection units nowadays step by step replace former used analog cathode ray tubes. These digital projection units are based on so-called microdisplays, which provide high resolution (computer video or HDTV resolution) on small areas (some square centimeters, pixel size 8–20 μm). Commonly used microdisplays are actually mainly based on two different technologies. The first one is the Digital Micro-Mirror Display (DMD) technique (see Fig. 1). In these displays, each pixel is a single mirror (e.g. size 16*16 μm²), which is electrostatically switched in dependence on the pixel information. The second technique, Liquid Crystal on Silicon Backplane (LCoS) (see Fig. 2), is very similar to a common LCD display, but the backplane is reflective.
The application field of microdisplays is – of cause – not limited to multimedia applications only. In optical metrology, they offer the possibility to provide an almost unlimited number of illumination patterns without changing slides or even the whole projector. Thus, new application areas in optical measurement techniques can be opened. For this purpose, high quality optical imaging systems are required: optical distortion reduction, high resolution, homogeneous illumination of the whole microdisplay, and high transmission rates are some of the necessary conditions to utilize these interesting new devices in optical metrology. Thus, optical design has to ensure these demands.

Concepts and Optical Design

As DMD displays have a mirror tilt of ± 10° (newer versions ±12°) they change the direction of incident light by 20°/40° (24°/48°, respectively), as can be seen in Figure 1. Thus, the illumination direction, the "on" and the "off" direction are separated by only 20° (24°), which has to be considered in optical design. Thus, the imaging system is quite large (length at least 120 mm), or a TIR-prism has to be used.

The principle optical setup for an LCoS display is quite different, as can be seen in Fig. 2. As the liquid crystal layer only changes the polarization direction of incoming light, a polarizing beam splitter is necessary to operate the display. This results – of cause – in a 50% loss of light intensity.
An optical design of an LCoS projector for optical metrology is shown in Fig. 3. In front of the beam splitter, optical filters are inserted to eliminate IR- and UV-light. This is important to protect the microdisplays against heat and high-energy rays (UV exposure can destroy the displays). On the side of the microdisplay, the rays of the imaging system can be assumed to be quasi telecentric.



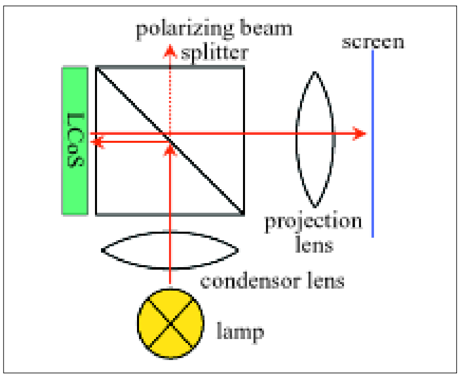


Fig. 2:
Reflective Liquid Crystal Display (LCoS), photo of the display and principle of the optical setup.

Realized Applications

Up to now, different applications of microdisplays in optical metrology have been realized, starting from the concept and the optic design, resulting in prototypes of the optics or in complete measurement systems. Some examples for completed products are given in the following list:

- 3-D measurement Systems, e.g. high speed 3-D digitizer "HSDig" /1/,
- Metrological Measurement Systems for Medical Applications , e.g. "kolibri-mobile" /2/,
- (Telecentric) measurement projection systems (see Fig. 3),
- Projection systems with automatic adjustable intensity distribution.

As the microdisplays offer a much wider variety of applications, this list can only illustrate some possibilities. But the developed concepts for optical design offer the possibility to adapt microdisplays quite easily to different tasks of optical metrology, in industrial and medical applications.

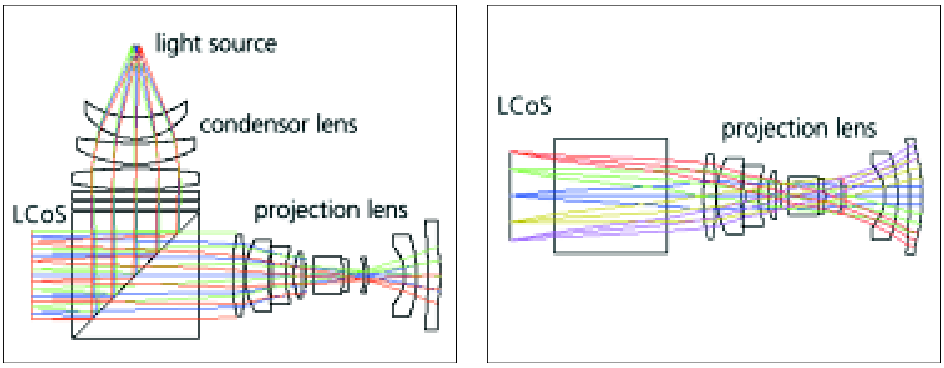


Fig. 3:
Optical design for a projection system for optical metrology (imaging distance 1600 mm) using an LCoS-microdisplay (15.4*19.2 mm², 1280*1024 pixel). Left side: illumination ray trace, right side imaging ray trace.

References

/1/ Kühmstedt P., Riehemann S., Gerber J., Notni G. "High speed 3-D-digitizer for CAD-CAM in industrial and dental applications" within this annual report
/2/ Notni G., Heinze M., Notni G., Reitemeier B., Fichtner D. "Optical 3-D-Scanning of extraoral defects using 'kolibri-mobile'" within this annual report

Radiation resistant VUV coatings for Excimer- and Free Electron Lasers

J. Heber, A. Gatto, and N. Kaiser

Fig. 1:
Development of Ultra Low Loss Evaporation Technology for radiation resistant VUV optics.

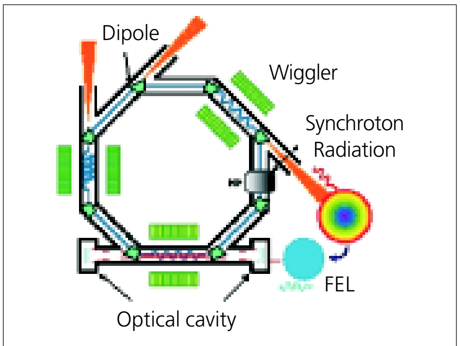


Fig. 5:
Typical set-up of a Storage Ring FEL. Electron bunches confined inside emit Synchrotron Radiation passing through the dipoles and wigglers. FEL optical cavity is shown.

Interference coatings for the vacuum ultraviolet spectral range (VUV) between 200 nm and 50 nm find several classical and innovative application fields in astronomy, semiconductor industry, synchrotron radiation optics, materials processing and medicine. Components comprise for example antireflective coatings, enhanced aluminum mirrors and broad band reflectors. Research on optical interference coatings, as the key element for resonant light amplification and laseroptics, has currently gained vital interest at VUV wavelengths. Up to the present day, absorption of optical crystals prevents generation of laser harmonics below 180 nm. Classical optical resonators, available from microwave down to UV wavelengths, meet strong material limitation at wavelengths shorter than 200 nm.
The operation of Excimer lasers, as unrivalled VUV sources, gives rise to several challenges for the VUV optical Research and Development. Indeed, for such wavelengths, strong radiation interactions exist. Origin comes from the high VUV photon energy which approaches the band gap of available coating materials. Therefore, radiation interactions can drastically degrade the components properties and thus limit or even kill any application field. Excimer laser optics has to withstand billions of pulses during long term industrial operation.
Obstacles to working in this spectral domain are numerous and must be overpassed. Equal challenges have to be met with Free Electron Lasers (FELs) which represent a next generation of accelerator based light sources, capable in principle of operating at any wavelength from the far infrared to the X-ray region. In the VUV region, FEL oscillators represent excellent light sources for scientific research, as soon as high quality mirrors are developed. Durability for this application requires resonator coatings to survive in a strongly harsh environment caused by the combination of high energy synchrotron radiation and residual gases from the cavity vacuum.
In 2001, new ultra low loss VUV technologies (Fig.1) have been developed at Fraunhofer IOF to optimize the laser radiation resistance of optical thin film elements. Only few known material combinations offer a desirable compromise of optical, absorption and scattering reduced, mechanical and chemical characteristics down to 120 nm. In collaboration with MIT Lexington, marathon irradiation tests (Fig. 2) have demonstrated the robustness of optimized VUV coatings.
Devoted and customized evaporation techniques brought out excellent performances down to 150 nm and even shorter (Fig. 3). In the context of European projects, the first phase of development of a FEL operating in the UV/VUV spectral range on the ELETTRA storage ring, high brightness synchrotron radiation source for the VUV/soft X-ray region, has recently been completed (Fig. 4). The project comprises several European programs involving institutes such as Sincrotrone Trieste, Fraunhofer IOF, CEA/LURE, CLRC-Daresbury Laboratory, the University of Dortmund , ENEA-Frascati, Institut Fresnel. In 2001, 560 mW power at 250 nm was measured at the European FEL project at Elettra with customized Transmission mirrors and lasing at 189.7 nm was obtained with High Reflection oxide mirrors, the shortest wavelength obtained so far with FEL oscillators (Fig. 4). Beyond the technological challenge, the project work at Fraunhofer IOF included the establishment of a reliable analysis technique as well as innovative coating designs.
Therefore, a complete DUV/VUV characterization setup has been developed, allowing photometric angle and polarization resolved reflection and transmission measurement down to 120 nm.

A coupled Excimer laser implemented on the spectrophotometer can be used for in situ sample irradiation and Reflection and Transmission measurements at 157 nm. Accurate evaluations and computing resources enable now the precise determination of the optical constants for relevant VUV materials.

Based on the results obtained, future research activities at Fraunhofer IOF will continue to pave the way for coating applications at VUV wavelengths, including the development of new laser source resonators and the design of VUV specific coating technology.

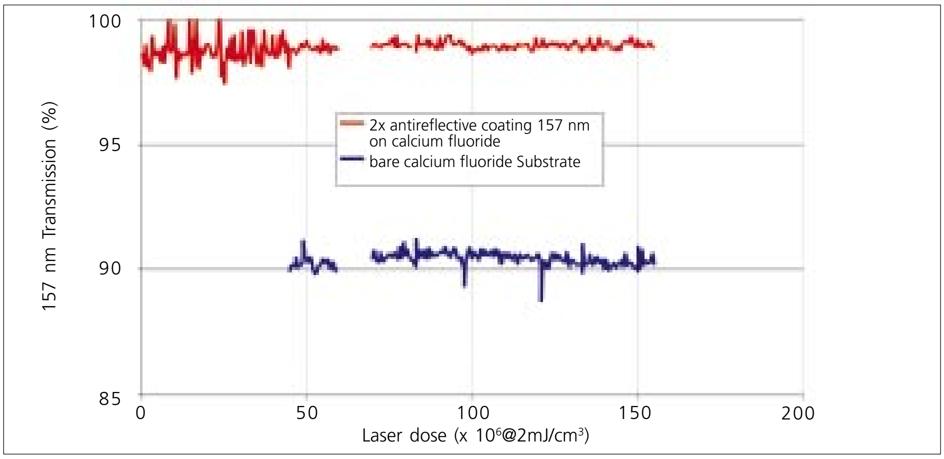


Fig. 2:
Durable VUV coating components
(example: 157 nm MIT Marathon Test): T (157 nm) = 99%, > $300x10^6$ pulses @2mJ/cm².

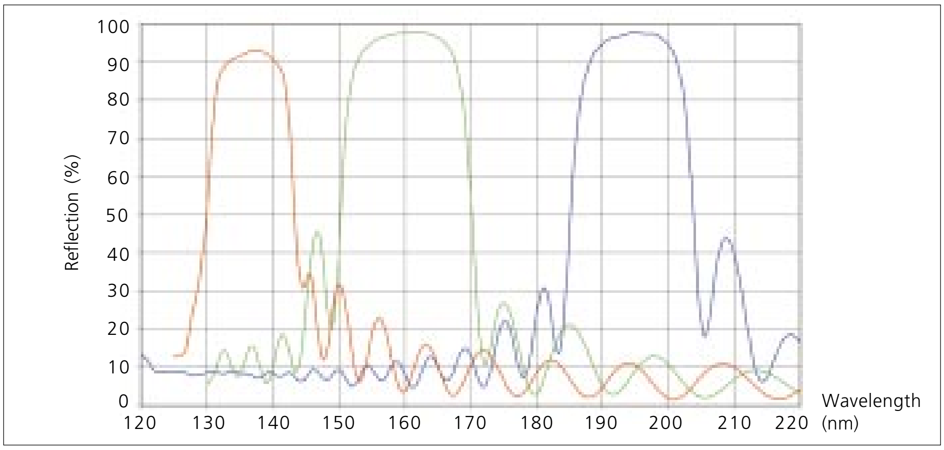


Fig. 3:
High reflective mirrors for the VUV spectral range.

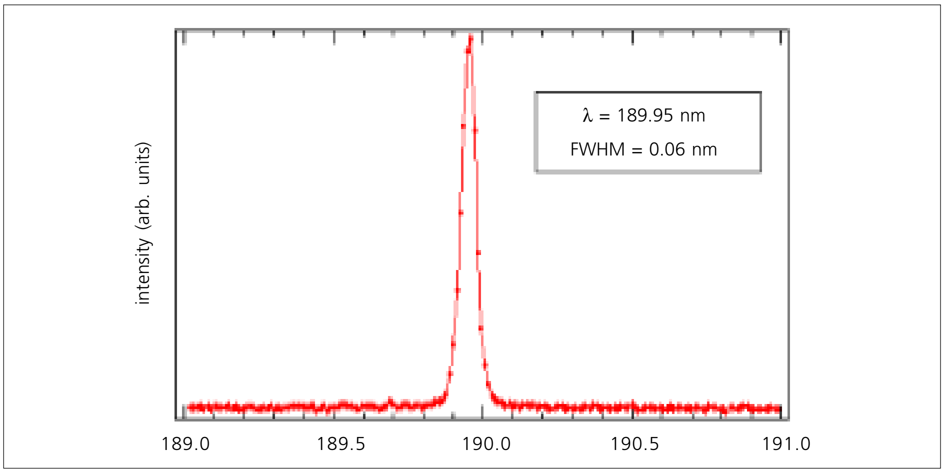
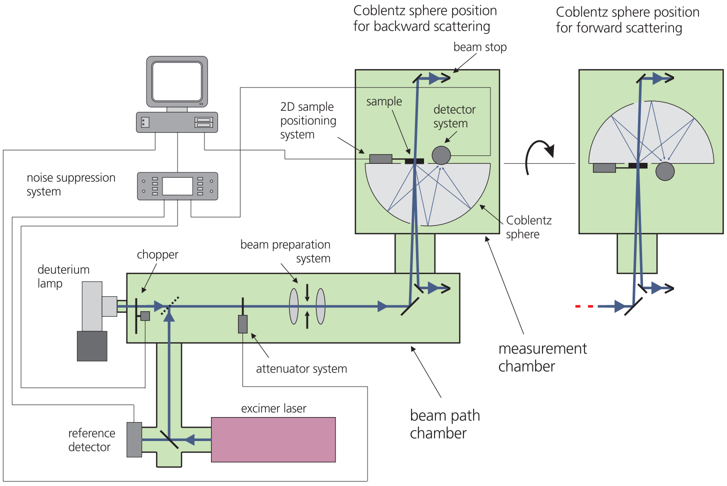


Fig. 4:
"In February 2001, the SRFEL on ELETTRA, Europe's first 'third generation' high brightness synchrotron radiation source for the VUV / Soft X-ray region, succeeded in lasing at 190 nm, representing a new world record for the shortest wavelength of a Free Electron Laser oscillator." Result obtained in the frame of European projects involving LZH (Germany), CEA SPAM and LURE (France) and the European project at ELETTRA.

Light scattering measurements on optical components at 157 nm and 193 nm

J. Steinert, S. Gliech, and A. Duparré



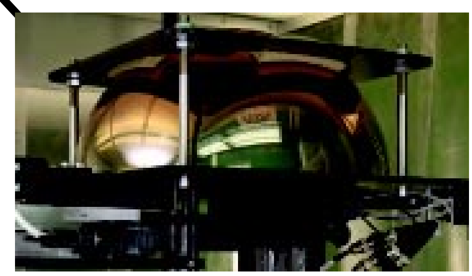


Fig. 1:
VUV measurement system, 157 / 193 nm. Photograph of the vacuum chambers (left), schematic diagram of the instrument (top right), and Coblentz sphere - position for total forward scatter measurement (bottom right).

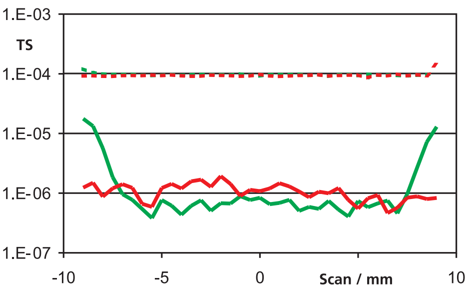


Fig. 2:
Background scatter levels of the VUV TS set-up at 157 nm in the forward (red) and backward (green) directions. The measurements were performed in purge gas (dotted line) and vacuum (full line).

The quality of optical thin film components is critically influenced by surface and interface roughness. With the ongoing trend of today's optical lithography towards ever decreasing wavelengths, the requirements for low-scatter optics in the DUV and VUV spectral regions and, in the long-term, at EUV wavelengths, are significantly increasing.
We report on an optimized instrumentation for total backscattering (TS-R) and forward scattering (TS-T) measurements of optical components at 157 nm and 193 nm. The design and construction of this instrumentation were driven by the industrial demands as mentioned above.
The TS-system, schematically shown in Fig. 1 (top right) and described in detail in /1/, is based on a Coblentz sphere (Fig. 1, bottom right). The Coblentz sphere images the light scattered into the backward or forward hemisphere within an angular range from 2° to 85° onto the detector according to ISO/DIS 13696 /2/.

High quality steel chambers (Fig. 1, left) for the collecting element and beam path can be operated in both vacuum and nitrogen atmosphere.
A specific technical arrangement allows for easy change from backscatter to forward scatter measurement, maintaining identical sample position and beam parameters.
The system was in particular optimized with respect to high resolution (low background scatter), fast and robust operation, and suitable purging/pumping regime. Although the system can be operated with an excimer laser as well as with a deuterium lamp, we mainly use the excimer laser, because this configuration enables the best performance.
The extremely low background scatter levels achieved for operation at 157 nm are depicted in Fig. 2. These signals represent detection limits of about 1×10^{-6} (1 ppm) in both the forward and backward directions at 157 nm and 193 nm for measurement in vacuum. If the system is purged with pure nitrogen, Rayleigh scattering by gas molecules increases the background level by about two orders of magnitude.
Measurements under vacuum conditions, however, can cause hydro carbon contamination of the sample surfaces and optical elements.
By suitably combining operation in vacuum and purge gas, Rayleigh

scattering at gas molecules and hydro carbon contaminations can be minimized.

For high performance optics it is essential to assure a constant quality over the whole sample area. A small diameter of the illuminating beam enables two-dimensional mappings of the total scattering with a spatial resolution better than one millimeter. This provides excellent information on the homogeneity of optical components. Fig. 3 shows a two-dimensional TS-mapping (λ = 157 nm) over the entire optically used area of a dielectric high reflective multilayer coating on CaF_2. The structures in this TS-diagram originate from inhomogeneities in the coating or particles and scratches on the substrate.

As a result of its transmission range extending to wavelengths as short as 120 nm, CaF_2 is gaining crucial importance in UV-optical applications. It has become the material of choice for many optical components of KrF (248 nm) and ArF (193 nm) excimer laser waver steppers, and is the main material for use at 157 nm. Fig. 4 displays a forward scatter mapping (λ = 157 nm) of a superpolished CaF_2 substrate. As a result of the high resolution of the measurement system even slight variations of the polishing quality across the surface can be clearly detected through the corresponding scatter level variations.

Beside the difficulties in high quality polishing of CaF_2, volume scattering from the CaF_2 bulk can also considerably limit the performances at 157 nm and 193 nm. To investigate volume scattering of CaF_2 substrates, we measured TS-T and TS-R at 193 nm on two identically polished CaF_2 substrates (Fig. 5). One sample (B) reveals drastically increased forward scatter losses indicating volume scattering in the bulk material of the sample since the surface finish was identical for both samples.

A two-dimensional mapping of the sample that exhibited volume scattering is also given in Fig. 5. The inhomogeneous scatter losses are caused by volume imperfections in the substrate material.

The extension of the system to angle resolved scatter (ARS), transmittance and reflectance (T, R) measurements has been constructed and is currently being implemented.

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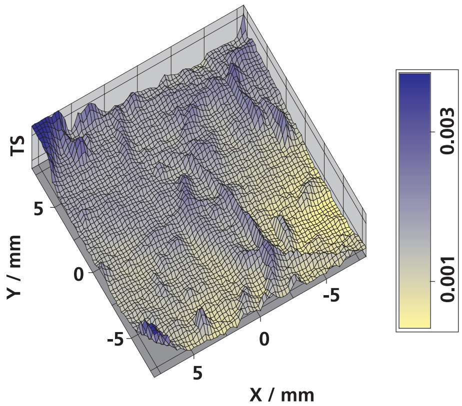

Fig. 3:
Two-dimensional backscatter mapping at 157 nm of a fluoride multiplayer HR system on CaF_2.

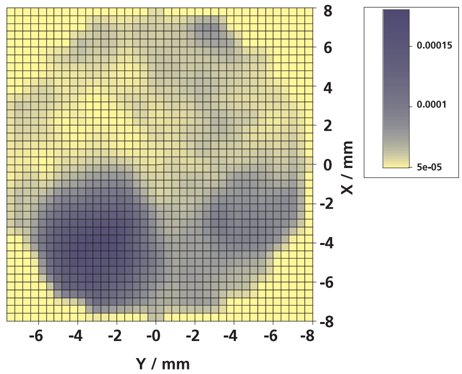

Fig. 4:
Forward scatter mapping at 157 nm of a superpolished CaF_2 substrate.

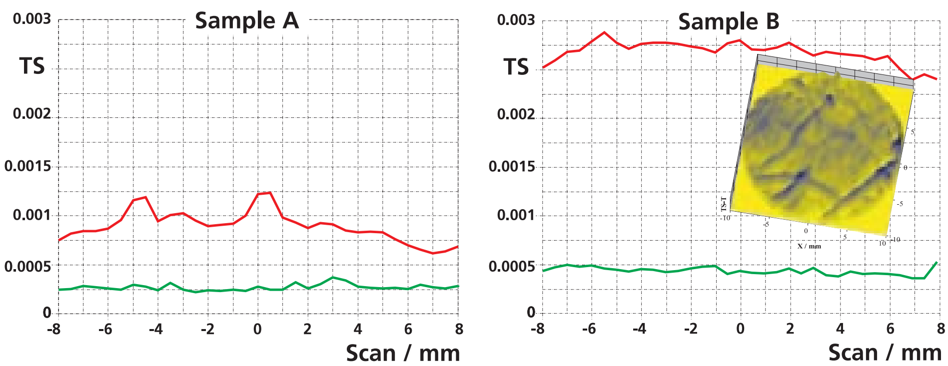

Fig. 5:
Forward scatter (red) and backscatter (green) scans at 193 nm of two identically polished CaF_2 substrates (A, B). One sample (B) shows noticeably increased TS-T – values indicating volume scattering from the bulk of the substrate.

New multilayer coatings for EUV optics

T. Kuhlmann, S. Yulin, T. Feigl, and N. Kaiser

Fig. 1:
The magnetron sputtering system Kenotec MRC 903.

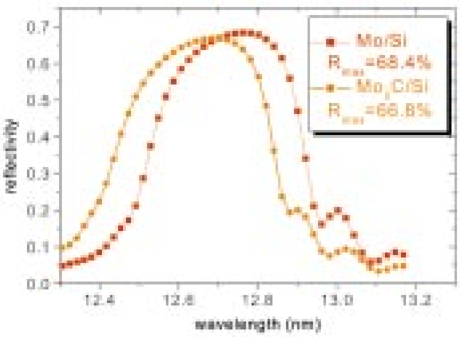

Fig. 2:
Measured EUV reflectivities of a Mo/Si multilayer mirror and a Mo_2C/Si multilayer mirror at normal incidence.

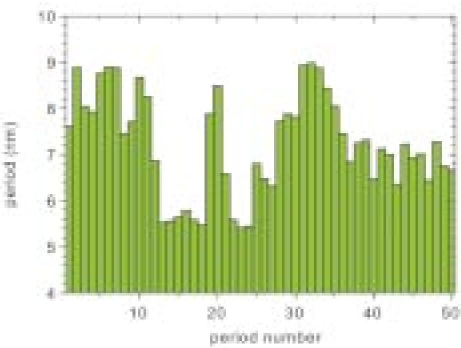

Fig. 3:
Period thickness distribution of a stochastic broadband multilayer mirror designed for high reflectivity up to 20° angle of incidence.

The good perspectives of extreme ultraviolet (EUV) radiation with a wavelength of approximately 13 nm to be applied in next generation lithography systems has led to a great progress in the development of plasma sources and optics for this spectral range recently. Since it is not possible to use lenses at these short wavelengths because of the strong absorption, optical systems must be entirely made up of mirrors. Actual designs for future EUV projection lithography tools contain 9 mirrors, i.e. the overall reflectivity of the system is given by R^9. Therefore, the task to optimize the throughput in future EUV Lithography systems has initiated big efforts to maximize the reflectivity of EUV multilayer mirrors. Using an industrial magnetron sputtering system (Fig. 1), we improved the reflectivity of Mo/Si multilayer mirrors to R = 68.4% by a successive optimization of all deposition parameters and the multilayer design. Simultaneously, the reflectivity of Mo_2C/Si multilayer mirrors was improved to R = 66.8% (Fig. 2). The Mo_2C/Si material combination excels in its thermal stability and therefore it is particularly suited to be used in applications with high thermal load, e.g. in the vicinity of a plasma source.

A serious drawback of multilayer coatings for their application in EUV optics is their limited range of reflectivity in the spectral and angular range. Firstly, the spectral FWHM of only 0.5 nm covers only a small part of the output of an EUV plasma source, and secondly, the fact that the reflectivity decreases significantly at angles of incidence of more than 9° causes big problems to use multilayer coatings on curved substrates. One solution of this problem is the fabrication of graded multilayer mirrors, i.e. coatings with a well defined lateral thickness distribution. However, such graded multilayer mirrors can be fabricated only in highly specialized and expensive coating machines and are actually limited to axially symmetric optics.

Apart from this, we designed and deposited broadband multilayer mirrors on the basis of a specific depth variation of the period. In all cases where maximum peak reflectivity is not required, e.g. in EUV metrology, astronomy and microscopy, broadband mirrors provide a useful alternative that is more easy to deposit than graded multilayers.

The lower reflectivity of broadband mirrors may be compensated by the use of large apertures that are possible due to the broad angular range of reflectivity.

The design of a broadband multilayer mirror for a broad angular range is shown in Fig. 3. The thicknesses of both the Mo layers and the Si layers vary over the whole multilayer stack. Using a thin film design program, the thicknesses in the multilayer have been optimized to fit the simulated reflectivity to a value of more than 30% in the angle of incidence range from 0° to 20°. Additionally, a more simple design with 3 different stacks (Fig. 4) was developed to meet the same requirement. The reflectivity of both mirrors was measured at the reflectometer of the Physikalisch-Technische Bundesanstalt at the synchrotron BESSYII in Berlin. The results in Fig. 5 show that both designs perform well and show a reflectivity of more than 30% up to an angle of incidence of 20°. The stochastic multilayer design is better suited to accomplish a constant reflectivity over a broad range due to its larger number of degrees of freedom, whereas the 3 stacks design is more easy to fabricate because only 3 sets of deposition parameters must be optimized and controlled.

The second task we focused on was to design and deposit a mirror that reflects EUV radiation in the whole wavelength range from 13 nm to 15 nm. The motivation for this development was the fact that some plasma sources that are developed by now in parallel to EUV optics show an emission spectrum that is much broader than the FWHM of a multilayer mirror, e.g. the emission of a Xenon gas plasma source. An optimum use of the output of a plasma source can be reached with special designed mirrors that are well adapted to the output of the source. The combination of such a broad plasma source with a broadband multilayer mirror outperforms a standard multilayer mirror concerning the integral reflectivity. With a stochastic design comparable to that in Fig. 3 a reflectivity of more than 15% was achieved for wavelengths from 13 nm to 15.15 nm (Fig. 6). Thus, the spectral bandwidth was increased by more than 4 times in comparison to a standard multilayer mirror. For comparison Fig. 6 also shows the normalized emission spectrum of a Xe plasma source developed at Fraunhofer ILT Aachen to demonstrate the good adaptation of the mirror reflectivity to the EUV emission of the source.

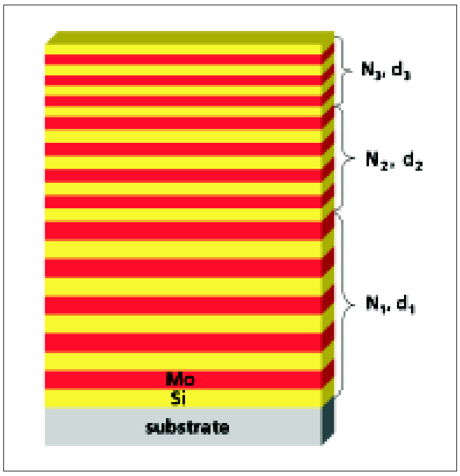

Fig. 4:
Schematic design of a broadband EUV multilayer mirror containing three different stacks: As well the number of periods as the period decrease from the bottom to the top stack of the multilayer.

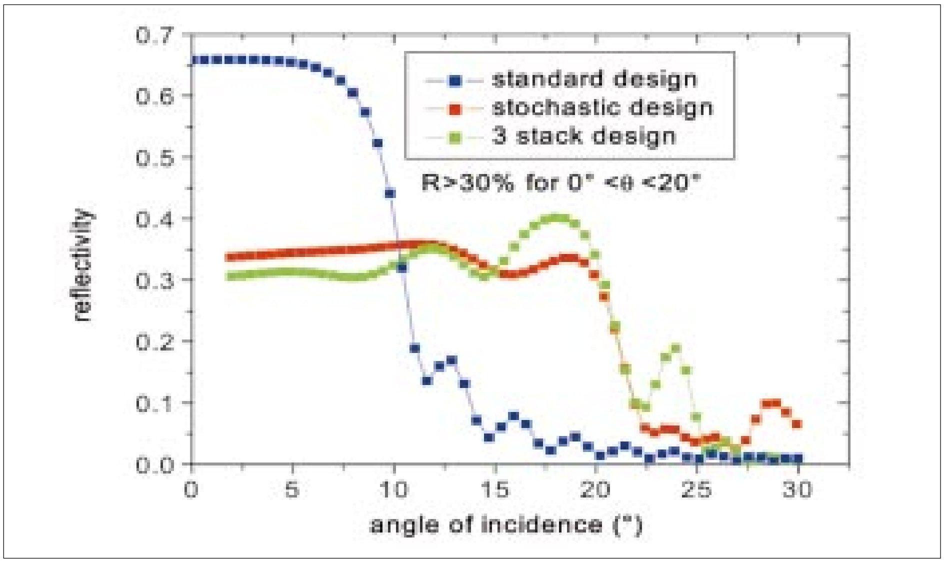

Fig. 5:
Measured EUV reflectivity of two different broadband mirrors in comparison to a standard multilayer mirror.

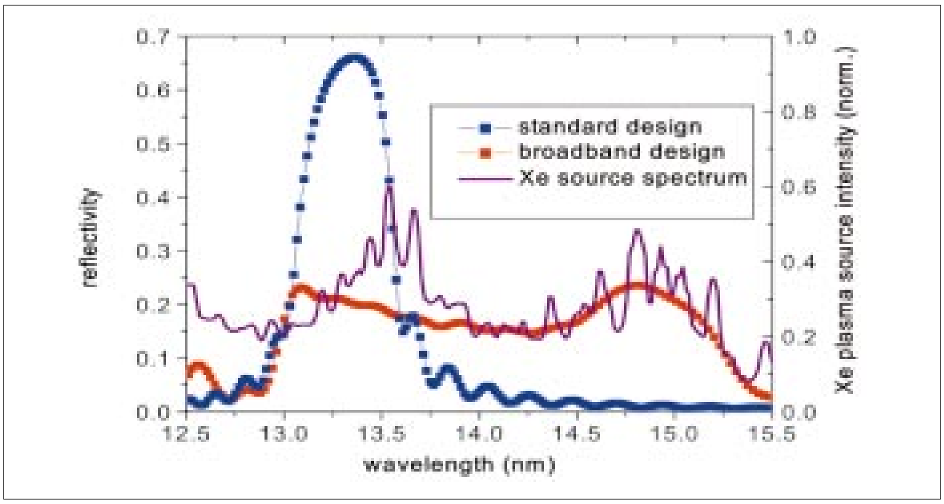

Fig. 6:
Measured EUV reflectivity of a broadband mirror designed for the wavelength range from 13 nm to 15 nm in comparison to a standard multilayer mirror. For comparison the normalized intensity of a Xe plasma source is shown (source: Fraunhofer Institut ILT Aachen).

Design and characterization of optical coatings with enhanced roughness for ultra-hydrophobic, low scatter applications

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* SuNyx Surface Nanotechnologies GmbH

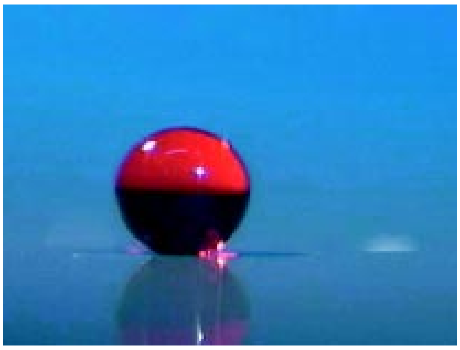

Fig. 1:
Water drop on an ultra-hydrophobic surface, contact angle = 174°.

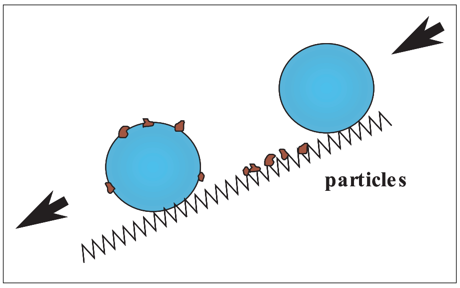

Fig. 2:
"Self-cleaning" by rolling water drops removing surface contaminations.

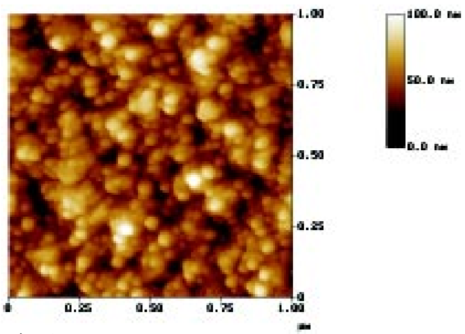

Fig. 3:
AFM image of the surface structure of the rough ZrO_2 layer deposited by e-beam evaporation.

Introduction

Studies into the wettability properties of solid surfaces are attracting drastically growing interest due to numerous new perspectives for practical applications. In particular, intensive research focuses on the development of hydrophobic surfaces. It has become well known that hydrophobicity depends on both the intrinsic material properties and surface morphology /1/.
Joint activities of SuNyx Surface Nanotechnologies GmbH and IOF are directed to a novel approach to create ultra-hydrophobic surfaces with the following properties:

- static contact angle considerably higher than 120° (Fig. 1), roll-off angle considerably lower than 10° (i.e. practically no adherence of water drops),
- real "self-cleaning", i.e., rolling water drops remove the surface contaminations (Fig. 2),
- surface morphology realized through enhanced statistical nanoroughness
- optically transparent with controlled scatter losses.

Usually, roughness in dielectric thin films constitute an undesirable property because it can result in scatter losses limiting the performance of the component. However, if enhanced roughness can be induced deliberately according to a quantified relation to contact angle as well as to an adjustable threshold for the resulting light scattering, then thin film roughness can be advantageously utilized to achieve the surface structure needed for ultra-hydrophobicity.

The coating technology is developed at SuNyx.
The contribution of the Fraunhofer IOF to this development focuses on the sample design and characterization.

Methodology

We have found that through wide-scale roughness analysis and subsequent data reduction the roughness characteristics can be directly related to the contact angle. As, on the other hand, vector scattering theories connect the roughness properties with scatter losses, a formalism has been accomplished, where both the wetting properties and scattering behavior can be expressed within the same "language" /2/.

The first step in this approach is the surface roughness determination of the thin film coating under study over a wide range of roughness spatial frequencies f, from 10^{-3} through 10^{3} μm^{-1}, which can be measured by combining white light interferometry, scanning force microscopy, and scanning tunneling microscopy /3/.
This is followed by calculating the Power Spectral Density PSD(f) for the whole frequency range and subsequent data reduction:

PSD(f) $\rightarrow$ amplitude spectrum A(f) $\rightarrow$ reduced amplitude spectrum b(f) $= A \cdot f \rightarrow$ logarithmically averaged reduced amplitude $I(\beta)$.

Our experimental investigations revealed that $I(\beta)$ can be empirically related directly to the contact angle and, hence, to the wetting behavior. Light scattering is predicted by using the measured PSD together with the optical parameters of the film, the wavelength of consideration etc. as an input into our multilayer vector scattering program /4/. The resulting scatter is compared with a threshold which in turn depends on the particular application. For architectural glass coatings, for instance, this threshold will be determined by a visual perception threshold of scatter effects in the visible spectrum.
Together with the parameter $I(\beta)$

then two essential criteria are provided for a coating to become a potential candidate for low scatter ultra-hydrophobic application.

Experimental results

First experiments have been made with zirconium oxide films as model layers. Single layers were deposited onto BK7 substrates by e-beam evaporation with varied deposition conditions and thicknesses to achieve different roughness properties. Total light scattering (TS), defined in detail in /3/, was measured on the samples as deposited, and contact angle was determined after overcoating the samples with a thin sputtered gold film and a monolayer of n-decanthiol to deliver the necessary intrinsic hydrophobicity. Note that this is only for contact angle measurement, in transparent sample applications other overcoatings such as thin perfluorinated films will be used instead.
The AFM image in Fig. 3 qualitatively reveals the enhanced roughness of a ZrO_2 layer evaporated at 590 K. The PSD curve for this coating is depicted in Fig. 4. The corresponding I(β) was > 0.3 and hence, a high contact angle could be predicted. Experimentally, a promising contact angle as high as 143° was obtained. Nevertheless, the light scatter losses remained reasonably low, as can be seen in Fig. 5 showing the results of forward and backward TS measurements at 633 nm.
For comparison, the PSD of another ZrO_2 layer deposited at ambient temperature has been also included in Fig. 4. The roughness characteristic of this coating was noticeably different, the calculated I(β) was considerably lower and so was the measured contact angle.

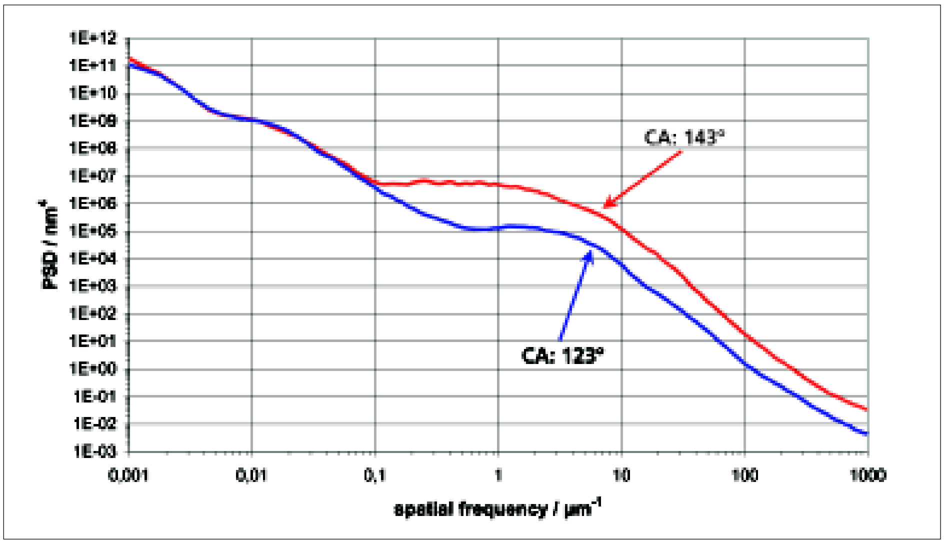

Fig. 4:
PSD curves and contact angles (CA) for ZrO_2 layers deposited by e-beam evaporation at different substrate temperatures, overcoated with a thin sputtered gold film and a monolayer of n-decanethiol.

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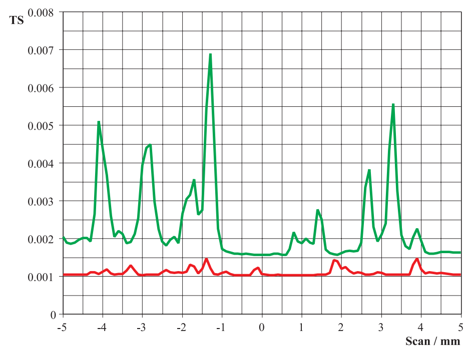

Fig. 5:
Total forward scattering (green curve) and backscattering (red curve) of the ZrO_2 layer which delivers a CA of 143°. Scatter measurements were performed at 633 nm.

Novel design for antireflection coatings

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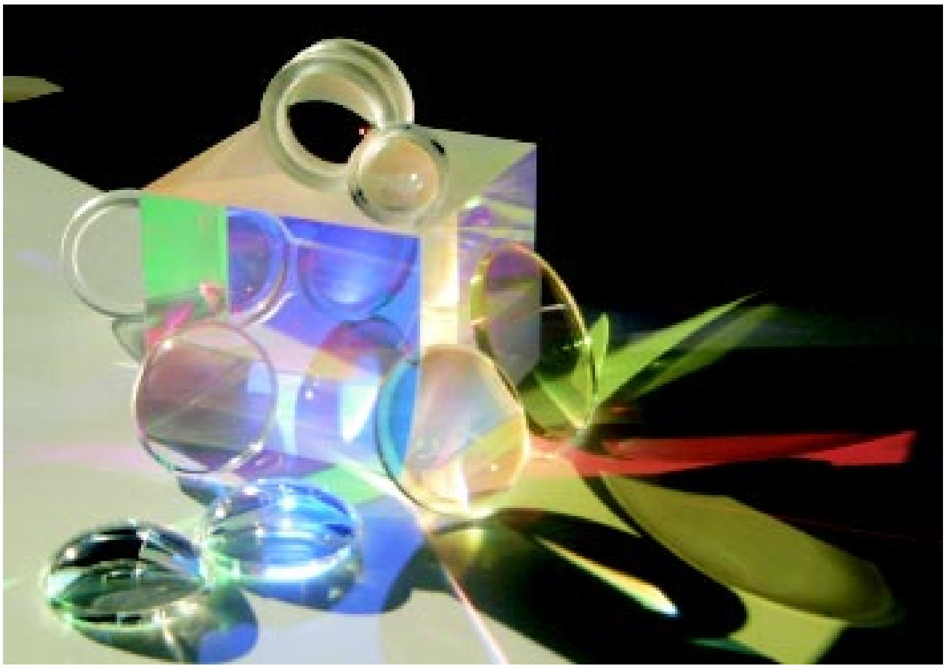


Fig. 1:
Scratch resistant and antireflection coated plastic lenses.

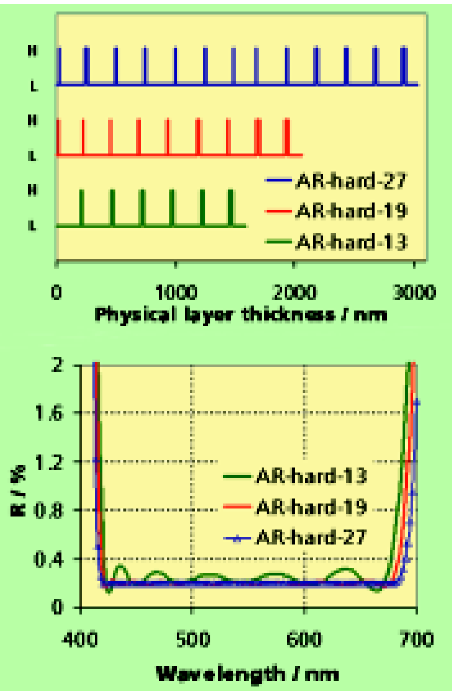


Fig. 2:
Index profiles and optical performances of designs AR-hard consisting of 13 (AR-hard-13), 19 (AR-hard-19) and 27 (AR-hard-27) layers. (substrate index n =1.49, back side disabled).

Coating of plastics for optical applications is intended to improve the mechanical durability of soft polymers and to provide an antireflection function. Hard scratch resistant coatings are not just interesting for spectacle lens manufacturers. They are also suitable for displays, such as used in automobiles, as well as for camera and endoscope lenses, which are need to be durable and achieve high light transmission (Fig. 1). Usually, a classical 4-layer antireflection system is added on top of a single layer hard coating therefore. On the other side there should be an increasing variety of different coating designs to realize a desired optical function if the total thickness of coating can be expanded. Aim of this work was to develop a broadband antireflection coating performing an average residual reflectance of about 0.4 % in the visible spectral range and an abrasion resistance as high as possible.

Physical thickness of coating had to be about 1 µm to 3.5 µm with minimized amount of the high index material. Considering this, needle optimization procedure has been used to design a novel type of thick antireflection coating by distributing the high index material in the whole stack instead of the usual combination of a very thick hard coating with a thin antireflection coating on top.

Needle optimization technique was applied starting with a total layer thickness of 1000 nm and a target value for residual reflection of 0.4 % in the spectral range 420 nm to 670 nm. The optimization procedure was interrupted after incorporation of 4 needle-layers. It was found, that the design can be modified to more or less layers. HL-layer pairs, where H is about 10 nm and L is about 245 nm, have to be added or removed border on the substrate side followed by design refinement. Uneven layer numbers between 7 and 35 at least are possible. Typically, the thicknesses of high index layers add up to less than 5 % of the total thickness and the high refractive material is almost evenly distributed over the multilayer system. We call the novel AR type "AR-hard". Figures 2 shows some possible index profiles and the resulting reflectance. An excellent uniform antireflection effect combined with high scratch resistance can be expected for the thicker coatings AR-hard.

It is obvious that the designs AR-hard may be regarded as periodic (or at least quasi-periodic) structures. Every period, consisting of approximately 5 nm to 15 nm Ta_2O_5 and about 240 nm SiO_2, has an optical thickness of three quarter-waves (QWOT) for a wavelength of nearly 516 nm, which is the reference wavelength of the designed coating. Reflection at this

wavelength is unchanged if L-layers will be reduced by optical thickness of one half-wave (excluding the last two layers). This type of AR-hard may be an alternative coating type for plastics if both antireflection at a single wavelength and high scratch resistance are required.
Coatings of new design type have been deposited on Topas®, Zeonex® and Polycarbonate using Plasma-ion assisted deposition. With coatings on both sides, transmission of thermoplastic materials was increased uniformly to more than 98 % in the visible spectral range (Fig. 3). Coated polymer parts withstand rubbing with steel wool (Fig. 4) and temperature changes between -35°C and +100°C. A low sensitivity of the AR-hard design type to systematic thickness errors of the high-index layers during the deposition process was observed. The low volume of high-index material inside of coatings of type AR-hard could be advantageously also for other spectral regions. Further modifications of the quasi-periodic design AR-hard can be expected for the future.

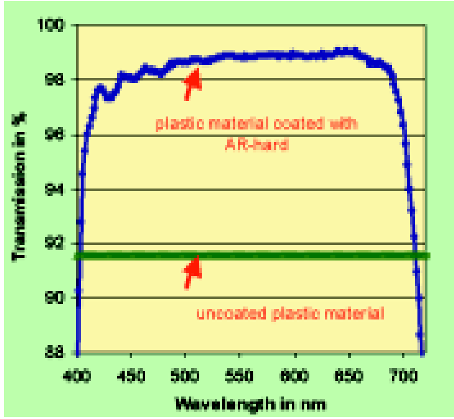
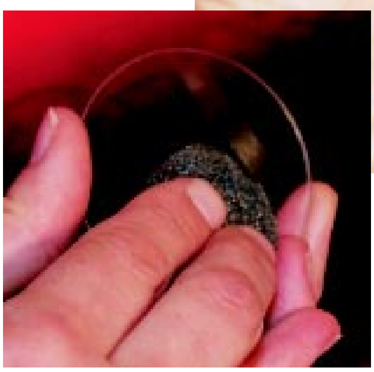


Fig. 3:
Transmission of Zeonex® before and after coating with AR-hard-27 on both sides.



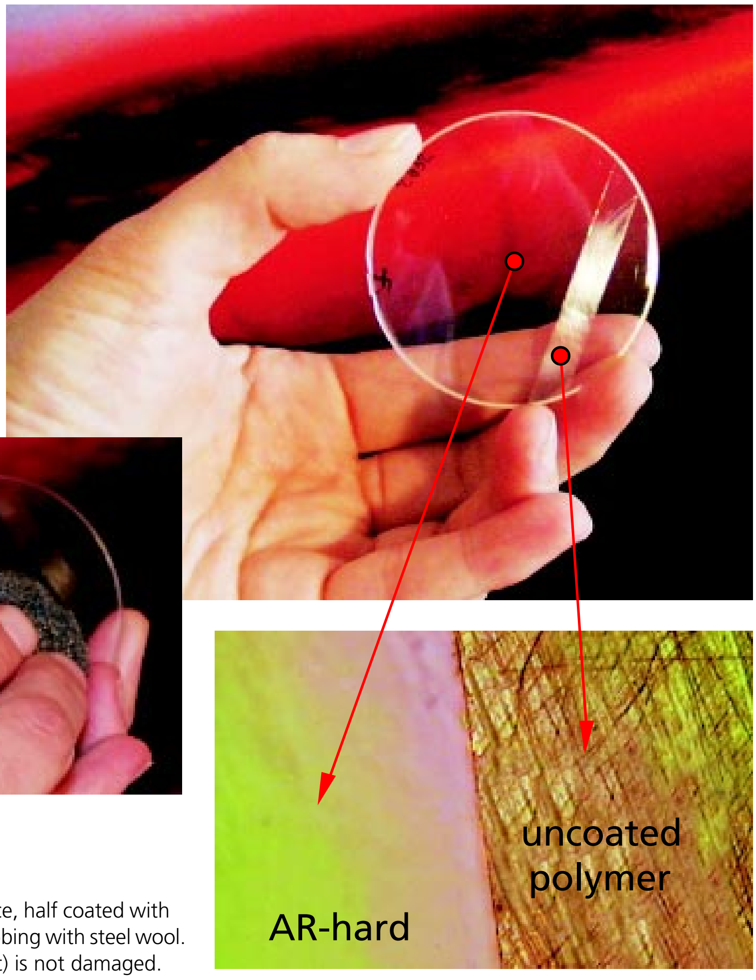


Fig. 4:
Polycarbonate surface, half coated with AR-hard-27 after rubbing with steel wool. The coated area (left) is not damaged.

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- Scientific Board of BioRegio Association (BioRegio Jena e. V.)

P. Kuehmstedt:
- Association of the German Precision Mechanics and Optical Industries (F+O Association), trade association imaging & photo technology

G. Notni:
- AMA association
- Editorial Board "Zeitschrift für Angewandte Gewässerökologie"
- VDI/VDE-GMA board 3.32. "Optical 3-D measurement"
- Association of the German Precision Mechanics and Optical Industries (F+O Association), trade association medical technology

T. Possner:
- DIN-Normenausschuss NAFuO, AA O21, "Integrierte Optik"
- ISO standardization committee TC 172/SC 9 WG 7 (microlens arrays)
- Program Committee MOC/GRIN
- Member of the European Optical Society (EOS)

R. Waldhaeusl:
- BioRegio Association (BioRegio Jena e. V.) – Member
- Working group for chemical and biological micro technique

Ch. Waechter:
- Program Committee "Integrated Optic Devices IV", Photonics West 2001
- Program Committee "Integrated Optic Devices V", Photonics West 2002

U. Zeitner:
- Referee for journals "Applied Optics", "Optical Engineering"

Science Fair Participation

Hannover Messe 2001
Micro Technology Thuringia
23.04.–28.04., Hannover, Germany
- Refractive beam shaper and homogeniser
- Refractive microlenses und microlens arrays
- Microfluidic components for chemistry and life sciences
- Micro-optical components made from polymers
- Design, development and assembly of microoptical systems
- Metrology systems and wafer holder for lithography applications

Control 2001
FhG – Fraunhofer Vision
08.05.–12.05., Sinsheim, Germany
- Selfcalibrating optical 3-D measurement system "kolibri"
- Eye-catcher "G-Scan", mobile multi-view 3-D measurement system with milling machine "digicut"

Laser 2001
FhG – Joined Stand
18.06.–22.06., München, Germany
- Microoptic assembly
- VUV scatter, transmittance, reflectance
- Surface and thin film characterization
- Complex micro-optic systems
- 3-D integrated optics
- Beam shaping of coherent and incoherent sources
- Coatings on polymers
- Coatings for the UV- and EUV spectral region
- Optical nanostructures

NanoBioTec 2001 Congress & Exhibition
BioRegio Jena e. V.
24.09.–27.09., Münster, Germany
- Microfluidic components for chemistry and life sciences
- Micro-optical components made from polymers

Biotechnica 2001
Research Location Thuringia
09.10.–11.10., Hannover, Germany
- Microfluidic components for chemistry and life sciences
- Micro-optical components made from polymers

K 2001
FhG – Joined Stand
25.10.–01.11., Düsseldorf, Germany
- Coatings on polymers
- Scratch resistant antireflection coatings

Productronica 2001
FhG – Joined Stand
06.11.–09.11., München, Germany
- Reference plate for lithography applications
- Automated alignment process and precision assembly
- Metrology system and wafer chuck

Conference and Exhibition on Micro & Nanoscale Technologies for the Biosciences 2001
27.11.–29.11., Montreux, Switzerland
- Microfluidic components for chemistry and life sciences
- Micro-optical components made from polymers

Euromold 2001
FhG – Rapid Prototyping
28.11.–01.12.,
Frankfurt/Main, Germany
- Selfcalibrating optical 3-D measurement system "kolibri"

Special Events

Winter school "Optical Thin Films"
08.–09. March 2001 in Tabarz

Workshop "Innovative Plastics for Optical Applications"
15. May 2001 in Jena

Design Course "Optical Coatings from Design through Manufacture"
19.–23. November 2001 and
26.–30. November 2001 in Jena

Patent Awards

100 11 649
Verfahren zur Herstellung eines Dünnschichtsystems
Feigl, T.; Yulin, S.; Stöckl, W.; Kaiser, N.

199 45 237
Verfahren und Vorrichtung zur Vereinzelung von ring- oder scheibenförmigen Bauteilen
Mohaupt, M.

199 20 033
Anordnung zur Erzeugung eines Laserstrahls hoher Leistung durch kohärente Kopplung der Laserstrahlungen mehrerer Laser
Pertsch, T.; (Glas, P.; Wrage, M.: Max-Born-Institut)

100 15 245
Optische Anordnung zur Symmetrierung der Strahlung von zweidimensionalen Arrays von Laserdioden
Göring, R.; Poßner, T.; Schreiber, P.

198 52 149
Vorrichtung zur Bestimmung der räumlichen Koordinaten von Gegenständen
Notni, G.; Schreiber, P.

198 28 498
Verfahren zum Messen und Verringern der Unwucht von rotierenden Körpern
Guyenot, V.; Kalkowski, G.; Risse, S.

198 12 786
Elektromechanische Vorrichtung zur Ausführung linearer Bewegungen
Höfer, B.; Pertsch, T.

197 54 529
Fingerfixateur zum Distrahieren von Fingern auf einer Kreisbahn
Damm, C.; Weber, B.; (Schmidt, I.; Markgraf, E.: Friedrich-Schiller-Universität Jena)

100 20 042
Vorrichtung zur Bestimmung der Haftfestigkeit von auf Substraten aufgebrachten Beschichtungen
Harnisch, G.; Schmidt, U.; Schulz, U.

Patent Pending

01/37439
Haftfeste optische Beschichtung auf strahlungsempfindlichen Kunststoffoberflächen
Kaiser, N.; Munzert, M.; Scheler, M.; Schulz, U.

01/37401
Verfahren zur Unterdrückung der Lichtstreuung an Spülgasen bei gleichzeitiger Unterdrückung von Kontamination und Ablagerungen beim Einsatz von Wellenlängen kleiner 200 nm
Duparré, A.; Gliech, S.; Notni, G.; Steinert, J.

01/37388
Segmentfassung für optische Elemente
Damm, C.; Kalkowski, G.; Peschel, T.; (Leitel, A.: CARL ZEISS Jena GmbH)

01/37361
Schichtdesign für EUV-Breitbandspiegel
Feigl, T.; Kaiser, N.; Kuhlmann, T.; Yulin, S.

01/37261
Spannungskompensierte, klimastabile oxydische Beschichtungen für ultrapräzise Beschichtungen
Gäbler, D.; Kaiser, N.

01/37157
Korsett
Damm, C.; Müller, E.; Peschel, T.; (Müller, T.: Klinik für Orthopädie Eisenberg)

01/37129
Verfahren zur Herstellung von Masken für die Beatmung von Patienten, Epithesen und Strahlungsapplikatoren
Notni, G., (Reitemeier, B.; Fichtner, D.: Technischen Universität Dresden)

01/37085
Zweiwellenlängenspiegel für UV-VUV Free Electron Laserstrahlung
Gatto, A.; Kaiser, N.; (Thielsch, R.: Southwall Europe GmbH)

01/37084
Verfahren zur Herstellung eigenspannungsfreier, reflektierender optischer Schichtsysteme auf Substraten
Yulin, S.; Feigl, T.; Kuhlmann, T.; Kaiser, N.

01/37067
Vorrichtung zur ein- und doppelseitigen Detektion von biochemischen Wechselwirkungen im Arrayformat
Bräuer, A.; Danz, N.; Waldhäusl, R.; (Kindervater, R.: GENE DISK AG)

Diploma Theses

Büttner, Alexander
Strahlhomogenisierung von LED´s mit Mikrolinsen
Friedrich-Schiller-Universität Jena, 01/01

Mann, Gunnar
Integration von Mikrooptik auf Wafern mit vertikal emmitierenden Lasern
Fachhochschule Jena, 02/01

Auch, Stefan
Charakterisierung und Optimierung mikrooptischer Komponenten für einen 1 auf 4 Single Mode Faserschalter
Fachhochschule Jena, 02/01

Zentgraf, Thomas
Messung von photonischen Bloch-Oszillationen in thermisch verstimmten Wellenleiterarrays
Fachhochschule Jena, 02/01

Lutze, Dennie
Untersuchungen zur Optimierung einer perkutan minimal-invasiv transplantierbaren Aortenklappe und deren Implantationstechnik
Fachhochschule Jena, 02/01

Lorenz, Jörg
Konzeption eines intramedullären Verriegelungsnagelsystems und Untersuchungen zu dessen Optimierung
Fachhochschule Jena, 04/01

Pogodzig, Jörg
Entwicklung eines Versuchstandes zur Charakterisierung von Stoßmagnetantrieben
Fachhochschule Jena, 12/01

Kummer, Frank
Entwicklung eines Greifers zur Handhabung eines miniaturisierten Plankonkavspiegels
Fachhochschule Jena, 12/01

Grünwald, Stefan
Untersuchungen zum Reibungs- und Verschleißverhalten von anorganisch-nichtmetallischen Werkstoffen und Schichten
Fachhochschule Jena, 06/01

Benkenstein, Tino
Mechanische Spannungen in Mo/Si-Schichtsystemen für den EUV-Spektralbereich
Fachhochschule Jena, 10/01

Müller, Cornelia
Herstellung und Charakterisierung von Multilayer-Spiegeln für den EUV-Spektralbereich
Fachhochschule Jena, 01/01

Flemming, Marcel
Experimentelle Untersuchungen zur Strahlformung und Signaldetektion im tiefen Ultravioletten Spektralbereich
Fachhochschule Zwickau, 10/01

Hong Wang
Oberflächenanalyse mittels Wavelet-Filter-Anpassung in C/C++ Umgebung
Technische Universität Ilmenau, 06/01

Dissertations

Risse, Stefan, Dr. rer. nat.
Ein Beitrag zur Entwicklung eines doppelsphärischen Luftlagers aus Glaskeramik
Technische Universität Ilmenau, 10/01

Scheller, Torsten, Dr. rer. nat.
Untersuchungen zu automatisierten Montageprozessen hybrider mikrooptischer Systeme
Technische Universität Ilmenau, 09/01

Publications

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Polymer Microfabrication Technologies
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Guyenot, V.; Tittelbach, G.; Siebenhaar, C.:
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In: Optical Interference Coatings, OSA Technical Digest (Optical Society of America, Washington, DC, 2001), ThA3-1 – ThA3-3, ISBN 1-55752-682-6

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Lecture: 7. Workshop Farbbildverarbeitung Erlangen 0ctober 2001

Büttner, A.; Zeitner, U.D.:
Strahlhomogenisierung von LEDs mit Mikrolinsen
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Dannberg, P.:
Mikrooptische Elemente für den Einsatz in optischen Faserschaltern
Lecture: ITG-Workshop Optische Aufbau- und Verbindungstechnik May 2001 Potsdam

Dannberg, P.; Bräuer, A.; Bauer, T.:
Microoptical and Waveguide Microstructures by UV-replication Technology for Optical Interconnects
Poster: Photonics West 2001, San Jose, USA

Dannberg, P.; Bräuer, A.; Göring, R.:
Replication for Precise Microoptical Structures
Poster: Micro & Nanoengineering (MNE) Jena 2001

Duparré, A.; Flemming, M.; Gliech, S.; Steinert, J.:
Technique for total scatter measurement at 157 nm and 193 nm
Lecture: SPIE's 46th Annual Meeting, Opt. Science and Technology, San Diego

Duparré, A.; Flemming, M.; Steinert, J.; Reihs, K.:
Optical coatings with enhanced roughness for ultrahydrophobic, low scatter applications
Lecture: Topical Meeting and Tabletop Exhibit, Optical Interference Coatings, 15–20 July 2001 Banff/ Canada

Duparré, A.; Notni, G.:
Messverfahren zur Untersuchung optischer Oberflächen für den VUV- bis IR-Bereich
Lecture: 1. Tagung "Optik und Optronik in der Wehrtechnik", 25–27 September 2001, Meppen

Duparré, A.; Steinert, J.:
Light scattering and roughness properties of DUV/VUV coatings
Lecture: Int. Wokshop on Optical Coatings, Erice,
24–28 September 2001

Duparré, A.; Steinert, J.:
Vermessung und Analyse von Nanostrukturen
Lecture: 2. Fachforum Nanotechnologie,
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Eberhardt, R.; Mohaupt, M.; Palm, S.:
Klassifizierung von Mikrobauteilen
Lecture: Abschlusspräsentation des Verbundprojektes Microfeed 2, Erfurt,
12–13 September 2001

Feigl, T.; Heber, J.; Gatto, A.; Kaiser, N.:
Optics Developments in the VUV-Soft X-Ray Spectral Region
Lecture: 23rd International Free Electron Laser Conference 20-24 August 2001, Darmstadt, Germany

Feigl, T.; Kuhlmann, T.; Yulin, S.; Kaiser, N.:
Design and fabrication of broadband and narrowband multilayers for EUV metrology
Poster: 3rd International Workshop on EUV Lithography 29–31 October 2001, Matsue-shi, Shimane, Japan

Feigl, T.; Yulin, S.; Kuhlmann, T.; Kaiser, N.:
Design, deposition and characterization of EUV multilayer at Fraunhofer IOF Jena
Lecture: Lawrence Livermore National Laboratory (LLNL) 6 August 2001, Livermore, CA, USA

Feigl, T.; Yulin, S.; Kuhlmann, T.; Kaiser, N.:
Damage resistant and low-stress Si-based multilayer mirrors
Poster: SPIE's 46th Annual Meeting, Conference Soft X-Ray and EUV Imaging Systems, 29 July–3 August, 2001, San-Diego, USA

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Damage Resistant and Low Stress EUV Multilayer Mirrors
Lecture: 2001 International Microprocesses and Nanotechnology Conference 31 October–2 November 2001, Matsue-shi, Shimane, Japan

Flemming, M.; Steinert, J.; Gliech, S.; Duparrè, A.:
Messtechnik zur Bestimmung des totalen Streulichts bei 157 nm und 193 nm
Lecture: 102. DGaO – Jahrestagung/ June 2001 in Göttingen

Gatto, A.:
Achromatic damage – Spectral-spatial dependance of the degraded optics
Lecture: TMR mid term review "Towards SRFEL at 200 nm"
20–22 February 2001, Rome, Italy

Gatto, A.; Feigl, T.; Kaiser, N.; Garzella, D.; De Ninno, G.; Couprie, M.E.; Marsi, M.; Trovo', M.; Walker, R.;. Grewe, M.; Wille, K.; Paoloni, S; Reita, V.; Roger, J.P.; Boccara, C.; Torchio, P.; Albrand, G.; Amra, C.:
Multiscale degradations of storage ring FEL optics
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High performance UV/VUV optics for the SRFEL at ELETTRA
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Gliech, S.; Duparré, A.:
Charakterisierung von lateralen Nanometerstrukturen mit optischen und nichtoptischen Messverfahren
Lecture: Posterabstrakt DGaO-Jahrestagung 2001

Gliech, S.; Duparré, A.; Notni, G.:
Streulichtmessanordnung zur Untersuchung von Oberflächen und Schichten für die Optik, Halbleitertechnik, Kunststoff- und Metallverarbeitung
Lecture: Symposium: DGaO Jahrestagung

Gorelik, T.; Kaiser, U.; Kuhlmann, T.; Yulin, S.; Glatzel, U.:
Transmission Electron Microscopy Study of the Cr/Sc Multilayer Structure
Lecture: A conference of modern Microscopical Methods, 9–14 September 2001, Innsbruck, Austria

Guyenot, V.:
Montageausrüstungen für hybride Mikrosysteme
Lecture: VDI-Kolloquium in Ilmenau, 09 January 2001

Guyenot, V.:
Montageequipments für hybride mikrooptische und mikromechanische Systeme
Lecture: VDI-Kolloquium in Schmalkalden, 10 January 2001

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Microassembly of Optics/Microoptics
Lecture: Ultra Precision Machining Seminar am 10 October 2001 Jena

Guyenot, V.; Eberhardt, R.:
Montage und Justierung mikrooptischer Bauelemente
Lecture: 305. Jenaer Carl-Zeiss-Optikkolloquium, 25 September 2001 Jena

Kaiser, N.:
Review of fundamentals of thin film growth
Lecture: 2001 Optical Interference Coating Topical Meeting, 15–20 July 2001, Banff Centre for Conferences, Banff, Alberta Canada

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Aktuelle Anwendungen von Nanoschichtsystemen in der Optik
Lecture: 2. Fachforum Nanotechnologie, Die Schlüsseltechnologie des 21. Jahrhunderts in der industriellen Anwendung, 23–24 October 2001 in Würzburg

Kaiser, N.:
Design optischer Schichtsysteme
Lecture: 4. Fachforum Schichten auf Glas – Herstellung, Eigenschaften, Mess- und Prüfmethoden, Anwendungen, 4–5 April 2001 in Regensburg

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Optische Schichten für den ultravioletten Spektralbereich
Lecture: 4. Fachforum Schichten auf Glas – Herstellung, Eigenschaften, Mess- und Prüfmethoden, Anwendungen, 4–5 April 2001 in Regensburg

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Eigenschaftsprofile optischer Oberflächen
Lecture: Tagung "Oberflächentechnik – Neue Anwendungsfelder für optische Funktionsschichten", 14 November 2001 in Mainz

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Einstellung maßgeschneiderter Eigenschaftsprofile optischer Oberflächen
Lecture: 102. DGaO Jahrestagung, 6–9 June 2001 in Göttingen

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Elektrostatische Chucks für Lithographie-Anwendungen
Poster: 308. Jenaer Carl-Zeiss-Optikkolloquium, 11 December 2001 in Jena

Kalkowski, G.; Risse, S.; Guyenot, V.:
Electrostatic Chuck Behaviour at Ambient Conditions
Lecture: MNE 2001 (Micro- and Nano-Engineering) Grenoble 16–19 September 2001

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Lecture: Workshop on Optical MEMS and Integrated Optics MEMS Workshop, Bommerholz June 2001

Kowarschik, R.; Notni, G.; Gerber, J.; Kühmstedt, P.; Schreiber, W.:
Trends in 3-D measurement with structured light
Lecture: Holo Met 2001, Balatonfüred, Hungary 24–27 June 2001

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Cr/Sc Multilayer mirrors for the Nitrogen Ka-line in the water window
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Neue High-Speed Projektionstechnik für die 3-D Koordinatenmessung
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Kühmstedt, P.; Notni, G.; Hintersehr, J.; Gerber, J.:
CAD-CAM-System for Dental Purpose – an Industrial Application
Lecture: FRINGE 01, 4th International Workshop on Automatic Processing of Fringe Patterns 17–19 September 2001 in Bremen

Laux, S.; Bernitzki, H.; Gäbler, D.; Kaiser, N.:
Beschichtung ultrapräziser optischer Oberflächen
Lecture: 102. DGaO Jahrestagung 2001 v. 6–9 June in Göttingen

Mohaupt, M.; Eberhardt, R.; Steinkopf, R.:
Handhabung von Mikrokomponenten Abschlusspräsentation des Verbundprojektes Microfeed 2 Erfurt, 12–13 September 2001

Müller, Th.; Hoch, A.; Eberhardt, R.; Gengenbach, U.:
Erste Ansätze für modular aufgebaute Greifer
Lecture: Statusseminar "Greiferbaukasten für die Montage von Mikrosystemen", 2002–2003, 08 November 2001, Productronica 2001, Neue Messe München

Munzert, P.; Schulz, U.; Kaiser, N.:
Zeonex® und Topas® in Beschichtungsprozessen – Wechselwirkung mit Plasma und Schichthaftung
Lecture: Tagungsband zum Workshop "Innovative Kunststoffe für optische Anwendungen", Jena May 2001

Munzert, P.; Schulz, U.; Kaiser, N.:
Beschichtung von Kunststoffen auf Cycloolefinbasis für optische Anwendungen
Lecture: Tagungsband zum zweiten oberflächentechnischen Kolloquium der Martin-Luther-Universität Halle-Wittenberg, June 2001

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Mikrospiegel in der optischen Messtechnik
Lecture: Werkstattgespräch Mikrospiegel – Anforderungen an die Technik von morgen, Dresden, 10 October 2001

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360-deg shape measurement with fringe projection-calibration and application
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3-D Messtechniken auf der Basis Streifenprojektion im produktiven Umfeld
Lecture: VDI Wissensforum Oberflächenprofilmesstechnik 27–28 September 2001 in Stuttgart

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Robuste optische 3-D Ganzkörpererfassung
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Lecture: Fraunhofer IPA Anwenderforum "Rapid Product Development", Stuttgart, 17 October 2001

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Switching in c^2 waveguide arrays
Lecture: NLGW, Clearwater, March 2001

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Anomalous light transport and diffraction control in waveguide arrays
Lecture: QELS Mai 2001 Baltimore

Peschel, U.; Leine, L.; Lederer, F.; Wächter, C.:
Bending the path of light with a microprism
Lecture: CLEO May 2001 Baltimore

Pröger-Mühleck, R.; Gebhardt, A.; Guyenot, V.; Schinköthe, Ch.; Siebenhaar, Ch.:
Aerostatisch gelagerter Impulsantrieb zur Präzisionsjustage in der Mikrotechnik
Lecture: GMM-Fachtagung Innovative Klein- und Mikroantriebe, Mainz 15 May 2001

Reitemeier, B.; Notni, G.; Fichtner, D.:
Optische Abformung extraoraler Defekte
Lecture: 13. Int. Symposium für Chir. Prothetik und Epithetik, Linz, 5–7 October 2001

Ristau, D.; Duparré, A.; et al. :
UV-Optical and Microstructural Properties of MgF2- and LaF3-Coatings deposited by Ibs and PVD Processes
Lecture and Poster: Topical Meeting and Tabletop Exhibit "Optical Interfernce Coatings" 15–20 July 2001 Banff/Canada

Rohrmoser, P.; Notni, G.; Kühmstedt, P.; Heinze, M.; Brakhage, P.:
Robust Volume Digitalization for Reverse Engineering Process Chains
Lecture: µ-rapid 28–30 May 2001, Amsterdam

Schreiber, P.:
Design und Herstellung refraktiver Strahlformer
Lecture: IIG-Workshop Optische Aufbau- und Verbindungstechnik May 2001 Potsdam

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Vakuumbeschichtung von Kunststoffen für optische Anwendungen
Lecture: Workshop "Innovative Kunststoffe für optische Anwendungen", Jena, May 2001

Schulz, U.:
Optische Schichten auf Glas und Kunststoff
Lecture: Seminar "Kunststoff- und Glasoptik", Technische Akademie Esslingen, 5–6 November 2001

Schulz, U.:
Optische Medien unter dem Gesichtspunkt anwendungsspezifischer Anforderungen
Lecture: Seminar "Kunststoff- und Glasoptik", Technische Akademie Esslingen, 5–6 November 2001

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Polycycloolefine – neue Polymere für die Optik
Lecture: Neues Dresdner Vakuumtechnisches Kolloquium (9. NDVaK), 18–19 October 2001, Dresden

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Thermoplastics in plasma-assisted coating processes
Poster: Optical Interference Coatings Topical Meeting, 15–20 July 2001, Banff, Canada

Steinert, J.; Ferré-Borrull, J.; Duparré, A.:
Extending the Capabilities of Scanning Probe Microscopy for Microroughness Analysis in Surface Engineering
Lecture: Usermeeting Göttingen, 10–11 April 2001

Steinert, J.; Duparré, A.; Flemming, M.; Gliech, S.:
Untersuchung der Lichtstreuung an Schichtkomponenten für 157 nm
Lecture: 102. DGaO-Jahrestagung/ June 2001 in Göttingen

Steinert, J.; Gliech, S.; Duparré, A.:
Measurement of total backscattering and forward scattering at vacuum-UV wavelengths
Lecture: 6th Intern. Workshop on Laser Beam and Optics Characterization 18–20 June 2001 München

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Instrument for light scatter measurements for 157 nm and 193 nm
Lecture: Topical Meeting and Tabletop Exhibit "Optical Interference Coatings" 15–20 July 2001 Banff/Kanada

Streppel, U.; Dannberg, P.; Wächter, C.; Bräuer, A.:
Realization of a vertical integration schema for polymer waveguides by a novel stacking technology
Lecture: Annual Meeting SPIE, August 2001 San Diego

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A novel fabrication technology for stached polymer waveguide devices
Lecture: ECIO April 2001, Proceedings

Streppel, U.; Dannberg, P.; Wächter, C.; Bräuer, A.; Nicole, P.; Fröhlich, L.; Houbertz, R.; Popall, M.:
Multilayer optical fan-out device composed of stacked monomode waveguides
Lecture: Annual Meeting SPIE, August 2001 San Diego

Streppel, U.; Dannberg, P.; Wächter, C.; Bräuer, A.; Nicole, P.; Fröhlich, L.; Houbertz, R.; Popall, M.:
Development of a New Fabrication Method for Stacked Optical Waveguides Using InorganicOrganic Copolymers
Lecture: First International IEEE Conference on Polymers and Adhesives in Microelectronics and Photonics, October 2001, Potsdam

Tikhonravov, A. V.; Trubetskov, M. K.; Duparré, A.; et al.:
Impact of systematic errors in spectral photometric data on the accuracy of determination of optical parameters of dielectric thin films
Lecture: Topical Meeting and Tabletop Exhibit "Optical Interference Coatings" 15–20 July 2001 Banff/Canada

Tikhonravov, A. V.; Trubetskov, M. K.; Duparré, A.; Tikhonravov, A. A.:
Influence of surface roughness on spectral properties of optical coatings
Lecture: Topical Meeting and Tabletop Exhibit "Optical Interference Coatings" 15–20 July 2001 Banff/Canada

Yulin, S.; Kuhlmann, T.; Feigl, T.; Kaiser, N.:
Damage Resistant and Low Stress EUV Multilayer Mirrors
Poster: SPIE's 26th Annual International Symposium on Microlithography, 25 February – 2 March 2001, Santa-Clara, USA

Zeitner, U.D.; Dannberg, P.:
Double-sided hybrid microoptical elements combining functions of multistage optical systems
Lecture: Annual Meeting SPIE, August 2001 San Diego

Zeitner, U.D.; Wyrowski, F.:
Design of hard-edged unstable laser resonators with userdefined mode shape
Lecture: Annual Meeting SPIE, August 2001 San Diego

Directions to Fraunhofer IOF

The Fraunhofer IOF is located in the former Carl Zeiss building called "Die Eule" ("The Owl") on the corner of Teichgraben and Leutragraben-Schillerstrasse.

By Train

To avoid confusion, realize that Jena has four railway stations or "Bahnhof": Westbahnhof, Saalbahnhof, Paradiesbahnhof and Bahnhof Göschwitz.

If you take the Frankfurt/Main–Dresden Intercity (IC) route, change trains in Weimar and leave the train at Jena-Westbahnhof.

If you take the Berlin–München (Munich) Intercity (IC) route, leave the train at Jena-Paradiesbahnhof.

From both railway stations you will reach the Fraunhofer IOF after a short downtown walk of approximately five minutes.

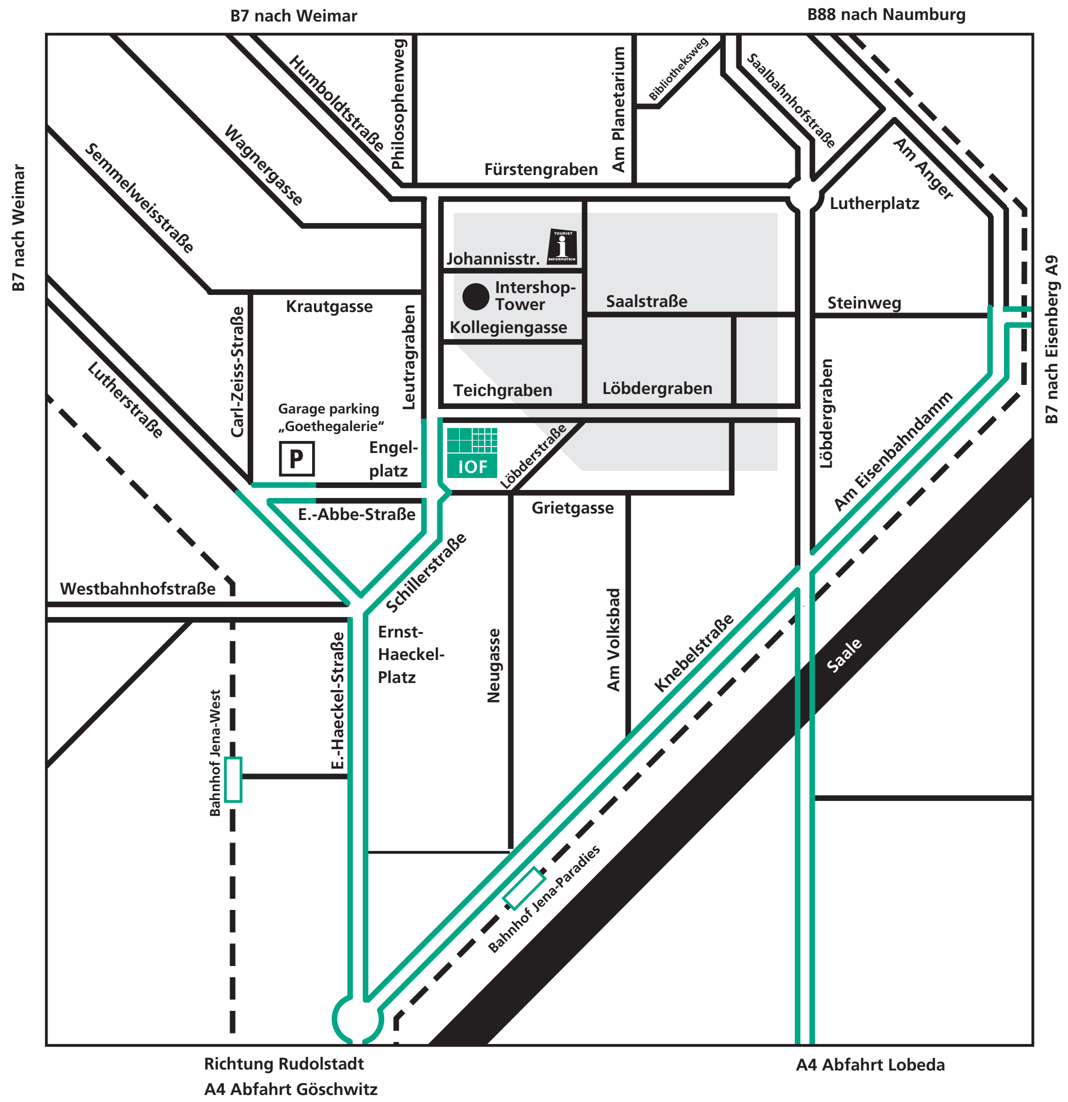
By Car

Leave the A4 motorway (Autobahn) at the Jena-Göschwitz exit, and drive to the city on the B 88 road. Just before Paradiesbahnhof, a small railway station on the right, you get to a small roundabout, where you take a slight left turn on to Haeckelstrasse. Proceed to the first traffic light and turn right on to Schillerstrasse.
On Schillerstrasse you pass the main post office on the left, and after one more block you will find the Fraunhofer IOF on the right hand side on the corner of Teichgraben, directly across from the Goethe Galerie shopping mall. Garage parking is available under the Goethe Galerie.

By Airplane

From the Erfurt airport, follow the signs directing you to the A4 motorway (Autobahn), exit Erfurt-Ost. On the A4 drive eastward (direction Dresden). Leave the A4 at the Jena-Göschwitz exit. Then follow the directions given above under "By Car".

From the Halle/Leipzig airport, follow the signs directing you to the A9 motorway (Autobahn). On the A9 drive south (direction Munich) until you reach the Hermsdorfer Kreuz intersection, then turn right and follow the A4 motorway westward (direction Erfurt). Leave the A4 at the Jena-Göschwitz exit. Then follow the directions given above under "By Car".



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Injection moulded microoptical module for a miniaturized 2-D position sensor