Fraunhofer IST

FRAUNHOFER INSTITUTE FOR SURFACE ENGINEERING AND THIN FILMS IST

COVER *Novel tool concept for finish processing of cylinder tracks: honing stone with pyramidal structure and rough CVD diamond coating.*

1

FOREWORD

Ladies and gentlemen,

the year 2017 was a very successful year for the Fraunhofer Institute for Surface Engineering and Thin Films IST in many ways with various innovative developments. We provide you with a selection of the most important events and latest research developments of the Fraunhofer IST in the annual report at hand.

We would like to take this opportunity to express our thanks to all people whose hard work and commitment made our success possible in the first place: above all the employees of the Fraunhofer IST, our partners from research and development, our customers from industry, our sponsors, colleagues and friends. Thank you for a trusting cooperation.

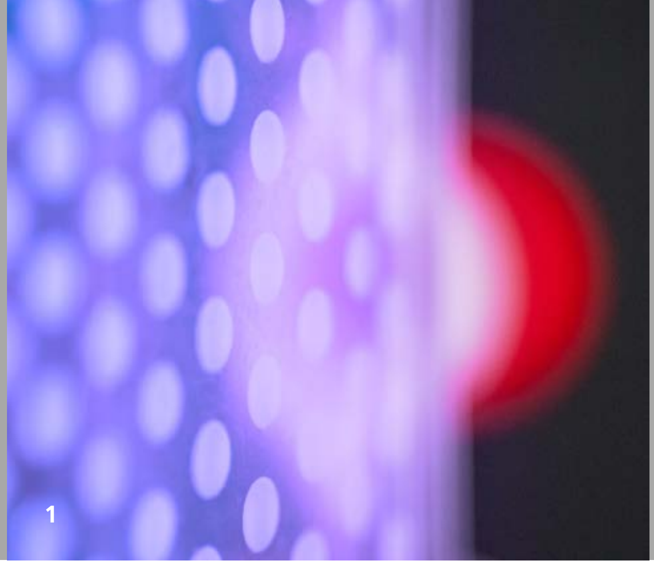
Dear reader, we hope you enjoy reading our annual report and are looking forward to your ideas for cooperation in future.

Prof. Dr. Günter Bräuer

Dr. Lothar Schäfer

1 *On the right: director Prof. Dr. Günter Bräuer, on the left: deputy director Dr. Lothar Schäfer.*

CONTENT



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2017 IN RETROSPECT

Machine tools and medicine – does not fit? Yes it does! At the Fraunhofer IST in the year under review once again we have shown that we are capable of bringing disparate worlds together.

"Plasma in a bag" the 2013 award-winning development for inner coating of closed bags, was one of the basic technologies for the current development of the prototype of a "laboratory in a bag". With LabBag® the Fraunhofer Institutes IST, IBMT, and IVV have developed a sterile all-in-one system for cultivation, differentiation and freezing pluripotent human stem cells, with this system not only can valuable material be obtained for regenerative therapies or for model systems for development of drugs, but time and money can be saved at the same time.

The project mentioned above is just one example of the innovation potential that we see at the interface of plasma technology and medicine. To even more intensively develop this potential in the future we have integrated the Director of Transplant Medicine of the Braunschweig City Clinic in our Institute. The objective is to initiate new projects here – wholly in keeping with the future strategic alignment of the Institute, which was decided at a conclave in March 2017, and where central significance was ascribed to "surfaces for medical technology". In this regard the focus areas are surface treatment, surface coating or surface functionalization of scaffolds, i.e. scaffold structures with which tissue can be cultivated, and disposable medical items.

Moreover, further strategic topics of the Institute were also identified; these include the coating of lightweight construction materials, additive manufacturing, adaptive glazing, and sensor applications for Industry 4.0.

Today our thin-film sensor technology is already one of our regular highlights and a magnet for visitors at the Hanover Fair, as it will be this year as well. However, use of thin-film sensor systems is not only interesting in the factory of the future; where the safety of buildings and bridges is concerned, the seemingly inconspicuous sensor structures also have a considerable potential. Safety, Industry 4.0, and digitalization are receiving increasing attention in Hanover, accordingly we observe a steady growing interest in our solutions in the area of simulation of processes and film systems. But also the IST's traditional topics, such as tribology, i.e. friction reduction, and wear protection have lost none of their topicality as the visitors of the Hanover Fair showed us once again in 2017.

The year 2017 was an anniversary year for the city of Braunschweig: With a Cloud of Science on the Burgplatz, together with the research region Braunschweig the city celebrated its 10th anniversary as a City of Science for two weeks. We were there 10 years ago and the Fraunhofer IST was present again last year, and among other showed the interested public how old silverware can be cleaned with plasma. In the concluding panel discussion with well-known representatives from the scientific and business communities our institute was able to convey its contribution to the topics of the future, such as the energy revolution and eMobility, to the Braunschweig public.

In a City of Science that is embedded in a research region, naturally one would also expect occasional spectacular regional projects. Currently there is such a collaboration between the IST and the Braunschweig scientists of the National Metrology Institute of Germany (Physikalisch-Technische Bundesanstalt, PTB): The international prototype kilogram is being redefined and in the future it should be derived from natural constants. This is necessary because the old reference standard, which has been in Paris since 1889, is losing mass. A silicon sphere is being produced at the PTB for this purpose. The silicon oxidizes on the surface, and this is precisely the problem, since the native layer silicon oxide coating grows slowly and unevenly. The Fraunhofer IST provides the solution: With our ALD coating plant for atomic layer deposition (ALD) an extremely thin and homogeneous quartz layer is applied on the surface in a reproducible procedure.

Another highlight from the IST should not go unmentioned in this context: After more than 15 years of preliminary research in the area of development of precision optical coating systems, in 2017 we finally achieved the breakthrough. The EOSS® coating system has been licensed three times and has been successfully placed in service at the customers' facilities. Thus, the Fraunhofer IST has become a reliable and competent partner of the plant manufacturers. In full accordance with the Fraunhofer idea, a prime example of technology transfer has been provided here. It works!

In this spirit it is my hope that you will find much inspiration and many exciting ideas for ambitious projects as you read our annual report.

Sincerely yours Günter Bräuer

1 *LabBag® – the "Laboratory in a bag" for cultivation of stem cells.*

2 *Various stages of production of a tool insert with sensor system for the manufacturing of natural-fiber reinforced plastics.*

3 *Silicon sphere coated by means of atomic layer deposition.*

BOARD OF TRUSTEES

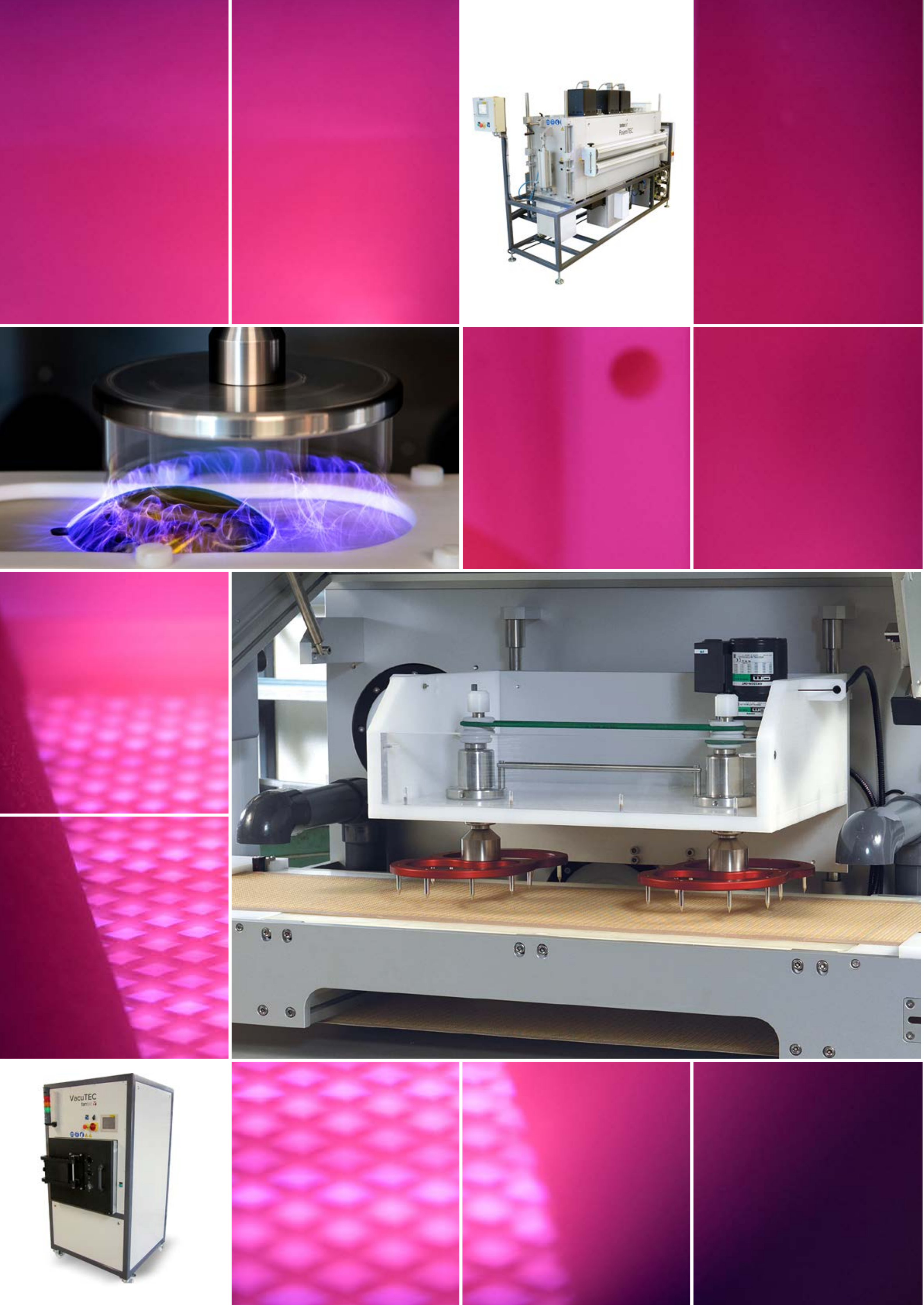
FROM THE BOARD OF TRUSTEES

Plasma technology is a vital key and cross-sectional technology that has been used in virtually all industries since the 1960s and since then its area of implementation has been continuously extended. Not least this is due to technological innovations such as the development of high-power impulse magnetron sputtering (HIPIMS). With these sputtering processes the plasmas that are used show a high proportion of film-forming ions, whose energy can be adjusted via a substrate bias. Thus film systems with improved but also completely new characteristics can be precipitated, which previously could not be realized with any other technology. For some time now high-power impulse magnetron sputtering has been implemented, further developed and brought to production maturity with great success at the Fraunhofer Institute for Surface Engineering and Thin Films IST. To increase understanding of the process and for optimization of the technology a number of very different HIPIMS generators are available in Braunschweig, here they can be combined with various industrial coating systems. Enhanced with outstanding competencies in the area of plasma diagnostics, plasma simulation, and process control, the institute is becoming a valuable partner for the industrial implementation of this technology.

For quite some time atmospheric pressure plasmas far away from the thermal equilibrium have been object of major scientific and also industrial interest. It is certainly advantageous that the technical complexity of the associated plasma systems is comparably low and that the area of implementation appears to be virtually unlimited. The Fraunhofer IST, with its R&D activities, takes full account of this so vital, innovative technological and also scientific trend in plasma technology. In recent years great progress has been achieved with these plasmas, particularly in the areas of medicine and life sciences; to which, with regard to its current application the Fraunhofer IST is entirely dedicated. Together with the Fraunhofer Institutes for Biomedical Engineering IBMT and for Process Engineering and Packaging, the IST developed a prototype for a "laboratory in a bag". In this transparent bag system, which is coated with IST technology, stem cells that are needed for regenerative therapies or as model systems for development of new medications can be cost-effectively, quickly cultivated, differentiated and frozen under sterile conditions. Currently scientists are working on its further optimization and are developing strategies for industrial implementation which the Board of Trustees is also following with great interest.

I look forward to exciting new results and not just in the areas cited above and express my best wishes to all employees of the Fraunhofer IST and the institute's executive board for every success in the year 2018.

Prof. Dr. Peter Awakowicz
Chair – Electrical Engineering and Plasma Technology
Ruhr University Bochum, Germany



OUTSTANDING COLLABORATION

Tantec A/S was founded in Denmark in 1974 and for over 40 years has been developing innovative plasma and corona solutions for the electrical pretreatment of plastic and metal surfaces for our customer's products; from small and complex medical instruments to components for the automotive industry and large plastic pipes. In this regard we can rely on a broad product spectrum of plasma sources, generators and monitoring systems, with which we work out customer-specific solutions, currently with 35 employees.

For more than 15 years there has been a successful cooperation with the Fraunhofer Institute for Surface Engineering and Thin Films IST. In recent years this cooperation has been continuously intensified through joint research projects and workshops. Here, in particular, the commitment, as well as the scientific and process engineering know-how of the Fraunhofer IST employees must be emphasized, which combined with the outstanding analytical and technical equipment, is characteristic of this institute.

Thus it has been possible to jointly develop many customer-specific solutions with great success over these 15 years. One example is the integration for pretreatment under a defined gas atmosphere in our Rototec-X technology. Through this integration high-quality plastics, such as PEEK, can be pretreated in such a manner that the bonding strength of adhesives is significantly increased.

In particular, new plastics or changes in the composition consistently pose major challenges for us as a plant manufacturer, since a change in material can cause pretreatment problems. In a project concluded recently the IST verified the negative influence of higher filler content on bonding strength and thus provided us with the prerequisite to solve the problem by retooling the equipment. Based on these positive experiences, since last year IST has been setting up a database for us.

Moreover, the fact that the Fraunhofer IST employees are constantly seeking new challenges is particularly noteworthy. Associated with the current exhaust emissions scandals, in the area of plasma technology again and again the question arises as to how much nitrogen oxide a plasma source generates. In order to provide customers with an answer to this question in the future, and in order to also offer processes that avoid the development of nitrogen oxides, a measuring apparatus for these purposes has been set up jointly with the IST.

These are just a few examples of our trust-based and outstanding cooperation over the last 15 years, for which I would like to sincerely thank all employees of the Fraunhofer IST. I also look forward to a continued successful partnership in the future.

Morten Thrane
Tantec A/S

INSTITUTE PROFILE

As an innovative R&D partner the Fraunhofer Institute for Surface Engineering and Thin Films IST offers complete solutions in surface engineering which are developed in cooperation with customers from industry and research. The IST's "product" is the surface, optimized by modification, patterning, and/or coating for applications in the business units:

- Mechanical engineering, tools and automotive technology
- Aerospace
- Energy and electronics
- Optics
- Life Science and ecology

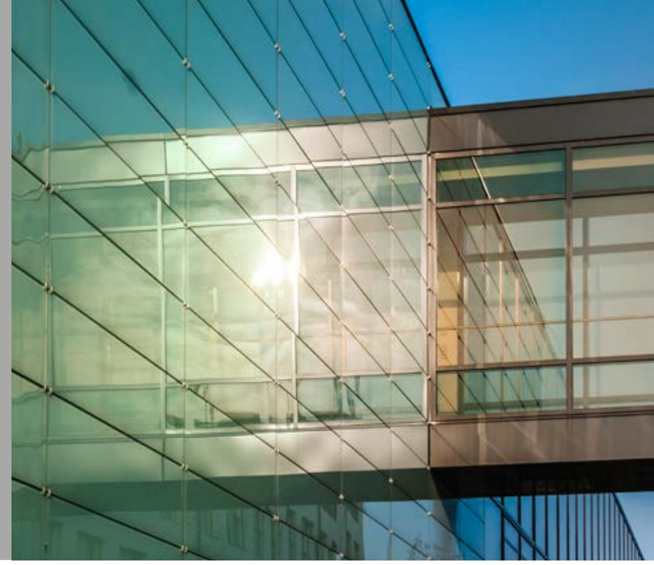
The principle technology units at the IST are atmospheric pressure processes with the main focus on electrochemical processes and atmospheric pressure plasma processes, low pressure plasma processes with the main focus on magnetron sputtering and highly ionized plasmas and PECVD as well as chemical vapor deposition with the main focus on hot-wire CVD. The center of tribological coatings focusses on the friction reduction, wear and corrosion protection. The Application Center for Plasma and Photonics deals with mobile plasma sources and laser plasma hybrid processes.

The IST's expertise lies in the ability to control all of the above-mentioned processes and their combination with a great variety of thin films. Extensive experience with thin-film deposition and film applications is complemented by excellent capabilities in surface analysis using the very latest equipment and in simulating vacuum-based processes.

Choosing the optimum combination of process and coating for a particular task is one of the major strengths of the Fraunhofer IST.

Besides fundamental research activities in cooperation with universities and research centers, around 120 employees are developing tailored surfaces and processes together with service providers, equipment manufacturers, and coating users from diverse industries. For an efficient technology transfer the IST offers a broad range of services, from development of prototypes and economical product scenarios to upscaling and even implementation of the technology at the customer.

At the site in Braunschweig the institute has an office and laboratory area of more than 4000 square meters. In addition, the new building of the Application Center for Plasma and Photonics provides 1500 square meters of office and laboratory area in Göttingen. The service offers of the Fraunhofer IST are supplemented by the competencies of other institutes from the Fraunhofer Group "Light & Surfaces" as well as by the Institute for Surface Technology of the Technical University of Braunschweig which is also managed by the IST director Prof. Dr. Günter Bräuer. Many projects are supported by funding through the state (Land) Niedersachsen (Lower Saxony) the federal government, the European Union, and other institutions.



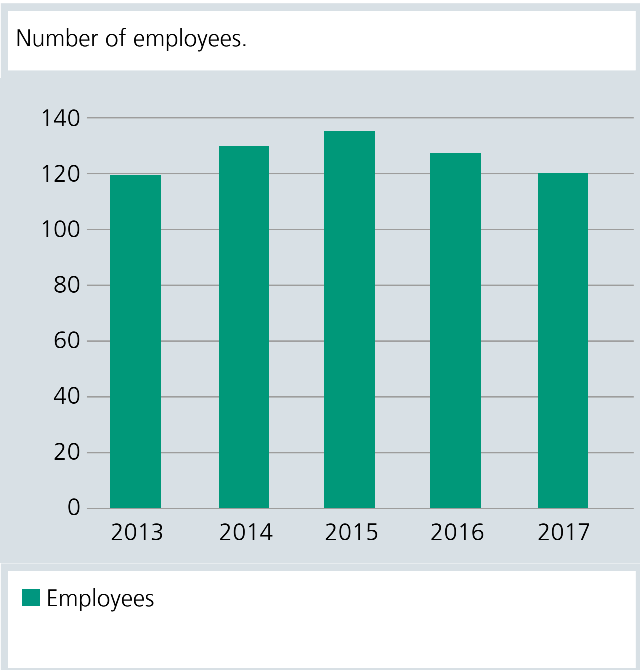
THE INSTITUTE IN FIGURES

Employee development
In 2017, the period under review, the Fraunhofer Institute for Surface Engineering and Thin Films IST had about 120 employees. Around 50 percent are scientific personnel, doctoral candidates and engineers. Research activities were supported by technical and commercial staff as well as a large number of graduands and student assistants. Training opportunities in the vocational fields of galvanics, physics and information technology were taken up.

Operating budget
2017 the operating budget resulted in a total operating budget of €12.0 million. About 30 percent of it were used for material-related costs. Corresponding the personal costs amount to €8.0 million.

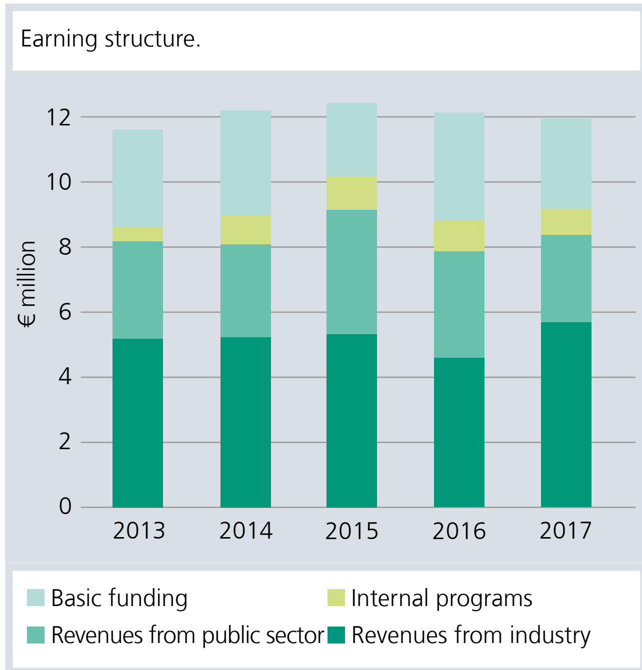
Earning structure
With €5.7 million revenues from industry the Fraunhofer IST has achieved a new record, the positive outcome is a relative increase of 49,4 percent. Additional €2.7 million were realized through public sector. In total, the institute has achieved external revenue amounting to €8.4 million.

Investments
All in all the Fraunhofer IST dispensed on investment some €750,000. Approximate €180,000 could be invested through external project funds. €300,000 can be attributed to normal investments. €270,000 were used for strategic investments. This means for the Fraunhofer IST an overall budget (B+I) totaling €12.75 million.

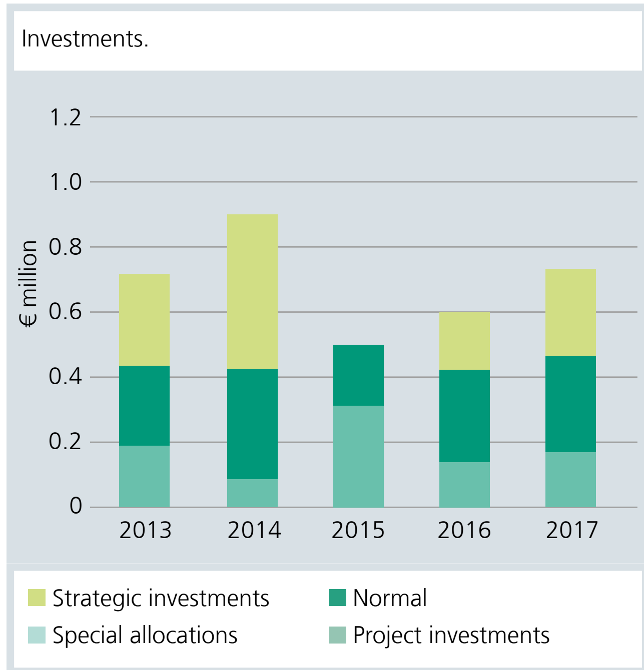


Number of employees.

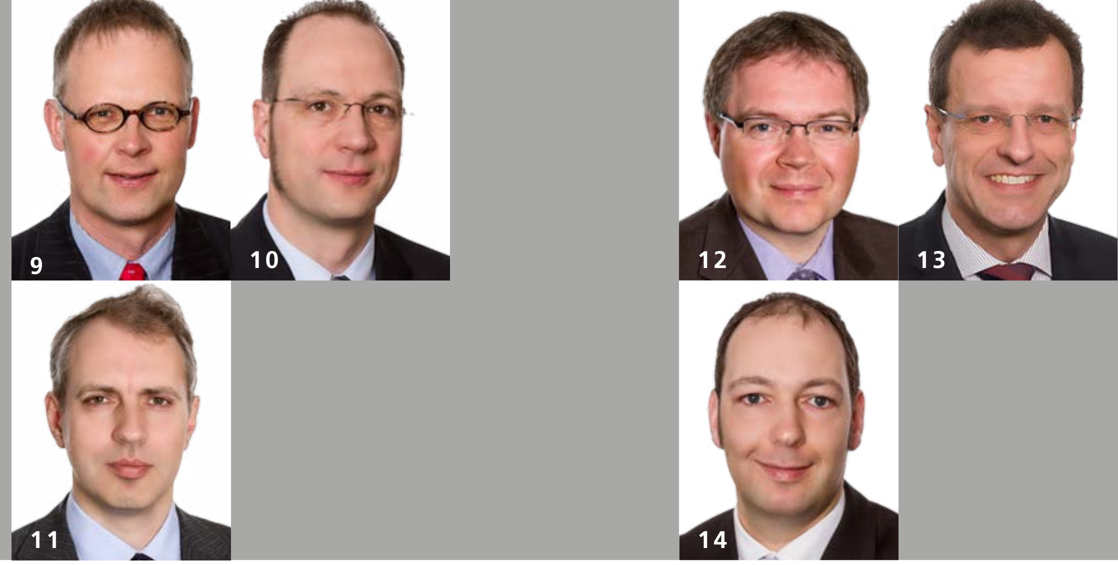
Personnel and material costs.



Earning structure.



Investments.



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Deputy director
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Magnetron sputtering
Large area electronics | Transparent and conductive coatings | Asset and process development | New semiconductor for photovoltaic and microelectronics

Highly ionized plasmas and PECVD
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Multifunctional coatings with sensors | High Power Impulse Magnetron Sputtering (HPIMS) | Micro tribology | Electrical coatings | Hollow cathode processes (HKV, GFS) | Plasma-enhanced CVD (PECVD)

Simulation
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Simulation of plants, processes and coating layer properties | Model based interpretation of coating processes

Chemical vapor deposition
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Tools and components | Diamond electrodes for electrochemical water treatment | Diamond coated ceramics DiaCer®

Dr. Markus Höfer[13]
Senior Scientist
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Atomic layer deposition
Product-related system construction | Coating and process development | Highly compliant coatings of 3D structures

Photocatalysis
Air, water and selfcleaning | Product evaluation and efficiency determination | Test engineering

Hot-wire CVD
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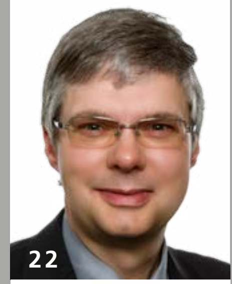
Diamond coatings and silicon-based coatings | Tool and component coatings for extreme wear resistance | Electrical applications for semi-conductors, barriers | Antireflective



Atmospheric pressure processes
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Electrochemical processes
Composites | Light metal coatings | Process development | Plastics metallization | Electrochemical processes

Atmospheric pressure plasma processes
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Microplasmas | Low-temperature bonding | Surface functionalization and coating | Plasma printing

Surface chemistry
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Biofunctional coatings | Polyelectrolyte coatings | Quantitative analysis of reactive surfaces | Photochemical processes

Center for tribological coatings
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System analysis and system optimization | Tribological coatings | Tribo-testing | Device conceptions

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Thin film sensors | Microstructuring 2D and 3D | Adaptronic systems

Tribological Systems
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Prototypes and small volume production | Plasma diffusion | Cleaning technology | Mechanical engineering and automotive technology | Carbon-based coatings (DLC) | Hard and superhard coatings | Wetting behavior | Tool coating (forming, cutting, chipping)

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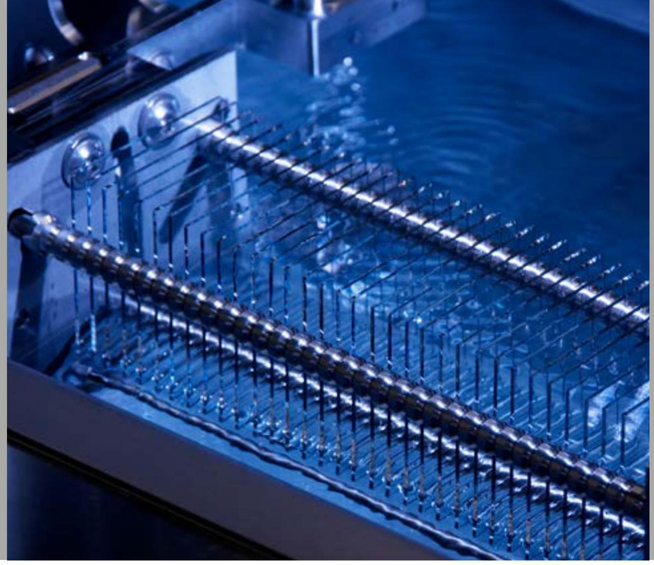
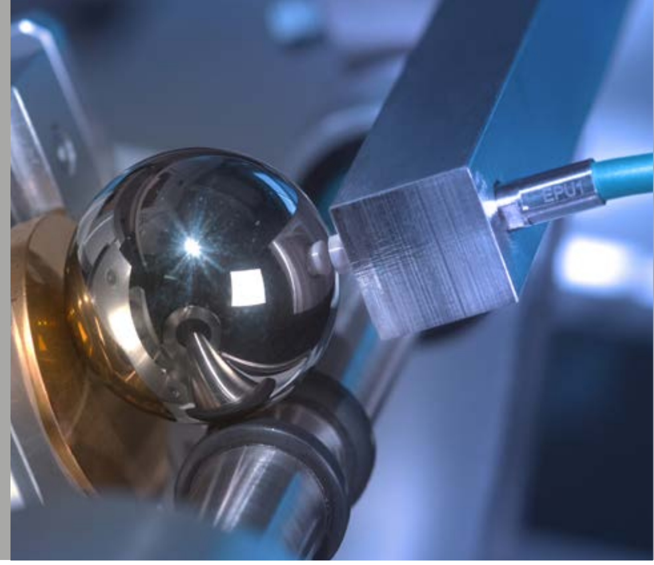
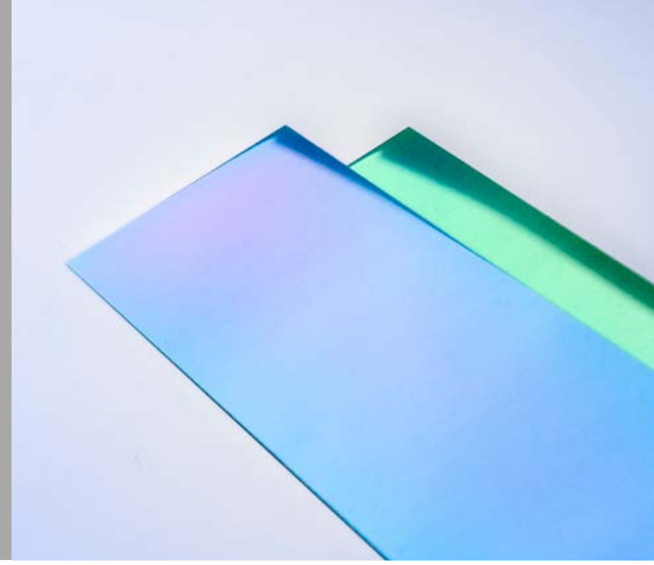


THE SCOPE OF RESEARCH AND SERVICES

Pretreatment – We clean surfaces

Successful coating processes imply a proper surface pretreatment. Therefore we offer:

- Effective aqueous surface cleaning including drying
- Special glass cleaning
- Plasma pretreatment and Plasma cleaning
- Plasma activation and Plasma functionalization
- Wet-chemical etching pretreatment
- Particle beam

Modification and Coating – We develop processes and coating systems

Thin films and specifically modified surfaces are the core business of the Fraunhofer IST. The institute utilizes a wide range of coating technologies and surface treatments, ranging from plasma coating and treatment in vacuum and at atmospheric pressure over hot-filament CVD processes to electroplating and laser technology. Our services are:

- Surface modification
- Development of coatings and layer systems
- Process technology (including process diagnostics, modeling and control)
- Simulation of optical layer systems
- Development of system components
- Process development
- Toolbuilding and plant engineering

Testing and Characterization – We ensure quality

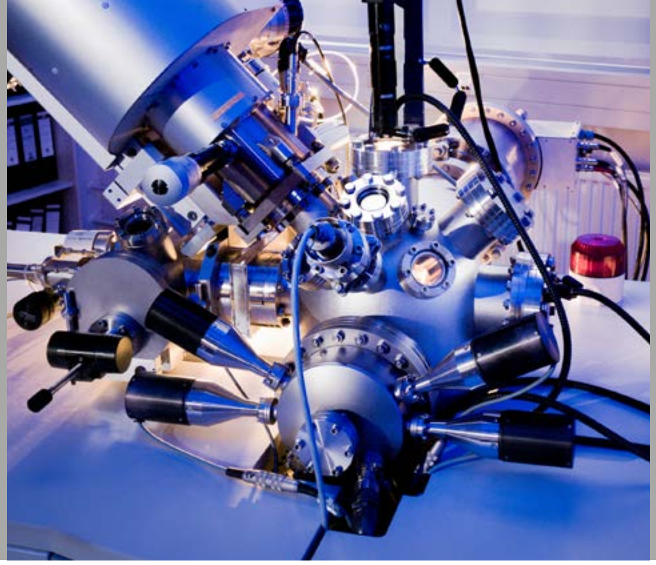
A fast and reliable analysis and quality control is the prerequisite for a successful coating development. We offer our customers:

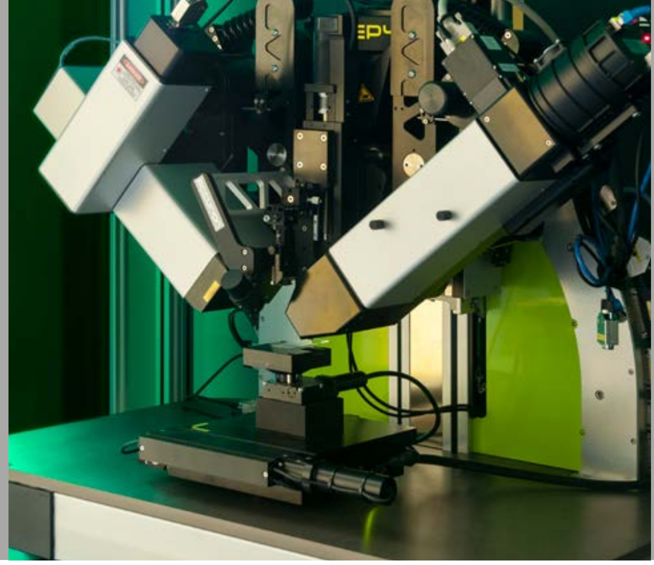
- Chemical, micromorphological, and structural characterization
- Mechanical and tribological characterization
- Optical and electrical characterization
- Testing of corrosion resistance
- Test methods and product specific quality control methods
- Rapid and confidential failure analysis

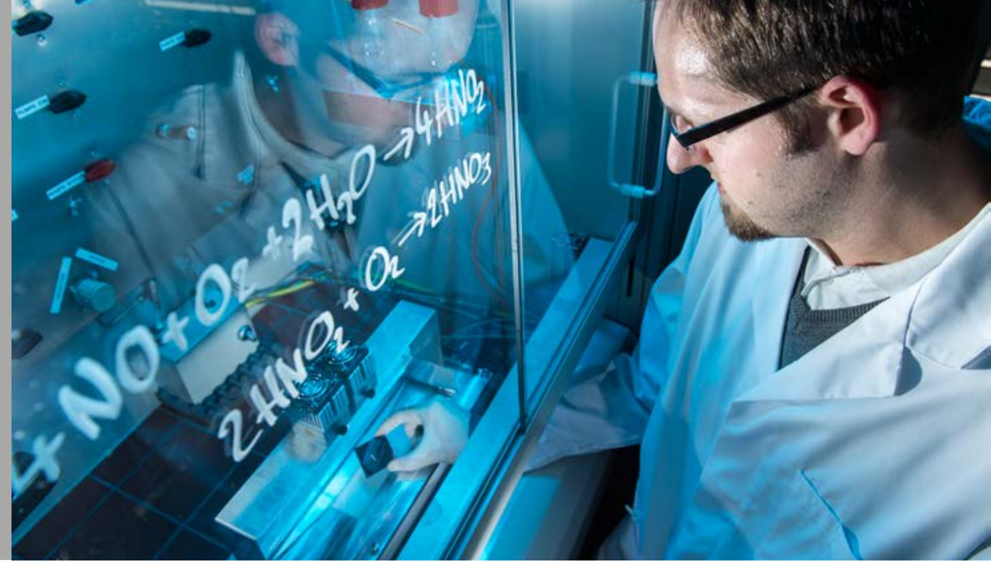
Application – We transfer research results in the production level

To guarantee an efficient technology transfer we offer a wide range of know-how:

- Cost-of-ownership calculations, development of economical production scenarios
- Prototype development, pilot production and sample coating procedures
- Equipment concepts and integration into manufacturing lines
- Consulting and training
- Research and development during production







ANALYSIS AND QUALITY ASSURANCE

Chemical and structural analysis

- Energy-dispersive X-ray spectroscopy (EDX)
- Electron microprobe (WDX, EPMA)
- Secondary ion mass spectrometry (SIMS)
- X-ray photoelectron spectroscopy (XPS)
- Glow discharge optical emission spectroscopy (GDOES)
- X-ray fluorescence analysis (RFA / XRF)
- X-ray diffractometer (XRD, XRR)
- FTIR spectrometry
- Raman spectrometry

Microscopy

- Scanning electron microscope (SEM)
- SEM with focused ion beam (FIB)
- Scanning tunnel and atomic force microscope (STM, AFM)
- FTIR microscope
- Confocal laser microscope (CLM)
- Photo optical microscopes

Mechanical tests

- Micro and nano indentation (hardness, Young's modulus)
- Rockwell and scratch test (film adhesion)
- Cross-cutting test, butt-joint test (film adhesion)
- A variety of methods for the measurement of film thickness
- A number of profilometers

Measurement of optical properties

- IR-UV-visible spectrometry
- Ellipsometry
- Colorimetry
- Angular-resolved scattered light measurement (ARS)
- Integral scattered light measurement (Haze)

Measurement of friction, wear and corrosion

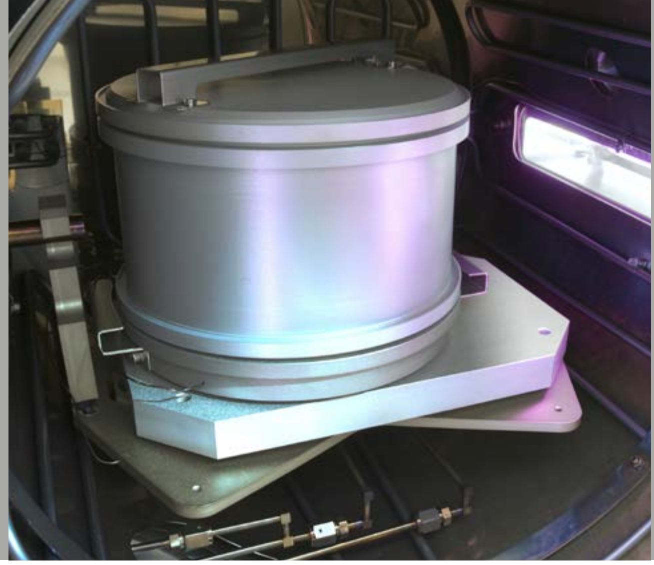
- Pin on disk tester
- Ball-cratering test (Calo)
- Wazau high-load tribometer (in air, in oil)
- CETR high-temperature tribometer (in air, in oil)
- Plint roller tribometer (in air, in oil)
- Taber abraser test, abrasion test, sand trickling test, Bayer test
- Microtribology (Hysitron)
- Impact and fatigue tester (Zwick Pulsator)
- Salt spray test, environmental tests

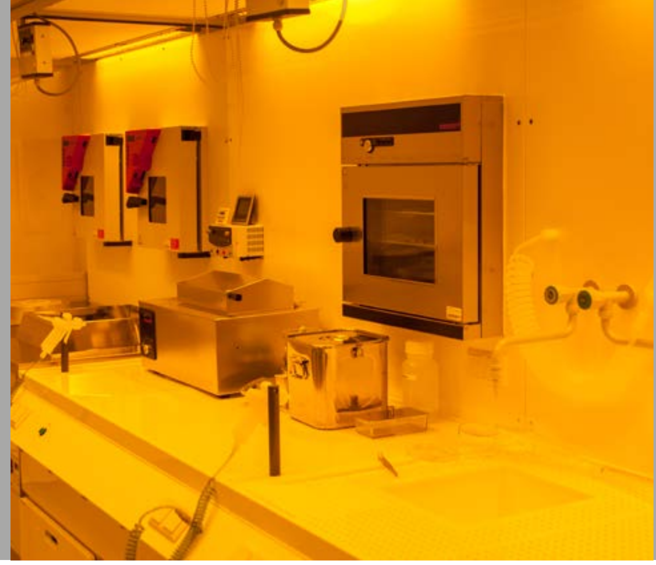
Specialized measurement stations and methods

- Characterization of solar cells
- Measuring station for photocatalytic activity
- Contact angle measurement (surface energy)
- Measuring systems for electrical and magnetic coating properties (e. g. Hall, Seebeck, conductivity, vibration magnetrometer VSM)
- Test systems for electrochemical wastewater treatment
- Measuring stations for the characterization of piezoresistive and thermoresistive sensor behavior
- Biochip reader for fluorescence analysis
- Layer mapping system (0,6 x 0,6 m^2) for reflection, transmission, Haze and Raman measurement
- In-situ bondenergy measurement
- Magnetic characterization (vibration magnetrometer VMS)
- Electrochemical measurement stations (CV measurement)
- Wet chemical rapid tests: colorimetrical determination of Ion and molecule concentrations
- Weathering tests: cyclical simulation of UV and rain exposition

Plasma diagnostics

- Absorption spectroscopy
- Photoacoustic diagnostics
- Laser induced fluorescence LIF
- High-speed imaging
- Optical emission spectroscopy OES
- Retarding Field Energy Analyzer RFEA
- Fiber thermometry
- Electrical performance test
- Numerical modeling





SPECIAL EQUIPMENT

- a-C:H:Me, a-C:H, hard coating production plant (up to 3 m^3 volume)
- Coating facilities incorporating magnetron and RF diode sputtering
- Sputter plant for high-precise optical coatings
- In-line coating facility for large-surface optical functional coatings (up to 60 × 100 cm^2)
- Industrial scale HIPIMS technology
- Plants for plasma diffusion
- Coating systems for hollow cathode processes
- Coating plant for thermal and plasma atomic layer deposition (ALD) (2D and 3D)
- Hot-filament-CVD units for crystalline diamond coatings (up to 50 × 100 cm^2) and for internal coatings
- Hot-filament-CVD unit for silicon-based coatings (batch process and run-through process up to 50x60 cm^2)
- Plasma-activated CVD (PACVD) units, combined with plasma nitriding
- Atmospheric pressure plasma systems for coating and functionalization of large areas (up to 40 cm widths)
- Microplasma plants for selective functionalization of surfaces (up to Ø = 20 cm)
- Bond aligner with an integrated plasma tool for wafer pretreatment in the clean room
- Roll-to-roll set-up for area-selective functionalization of surfaces up to 10 m/min
- Machine for internal coating of bags or bottles
- Laser for 2D and 3D microstructuring
- Automated system for deposition of polyelectrolyte
- 2 mask aligner for photolithographic structuring
- Laboratory for microstructuring (40 m^2 clean room)
- System for electroplating metallization of waveguides (11 active baths with a volume of each 140 l and 1 nicke bath with a volume of 400 l)
- Modular technical electroplating system (20 stations for active baths with a volume of each 20 l)
- Anodizing plant (11 active baths with a volume of each 140 l and 2 anodizing baths with a volume of each 350 l)
- 15-stage cleaning unit for surface cleaning on aqueous basis
- Clean room – large area coating (25 m^2)
- Clean room – sensor technology (35 m^2)
- Laser structuring laboratory (17 m^2)
- Mobile atmospheric pressure plasma sources
- Nanosecond dye laser (Nd: YAG-Laser)
- CO_2-laser and Excimer-Laser
- EUV spectrography
- Semiconductor laser
- Picosecond laser

SUSTAINABLE SOLUTIONS WITH SURFACE AND THIN FILM ENGINEERING

Sustainability is currently perhaps the most important social guiding principle of the age. Not only in the European Union but also in Germany sustainable development processes are in first place on the agenda. In the field of surface and thin film engineering the Fraunhofer IST has been developing solutions for sustainable products and sustainable industrial production for a number of years now.

A large number of research subjects at the Fraunhofer IST are oriented by urgent future-related topics and by social trends, such as the implementation of an alternative energy supply, alternatives for scarce materials and raw materials, or mobility in the 21st century. The very thinnest high-performance coatings are in addition the basis for a variety of further products and high-tech applications which are viable for the future, especially when it is a matter of saving material and energy. Some examples from our research into sustainable industrial products and processes:

Innovative materials

- At the Fraunhofer IST intensive research has been in progress on replacing indium tin (ITO) with alternative materials such as ones based on ZnO and SnO_2 and TiO_2.
- Low damage separations of indium free materials for high efficient LEDs are being developed.
- At the Fraunhofer IST alternative materials for the high-refractive-index tantalum oxide coatings used in optical industries are being developed.
- New materials like canal materials for TFIs and p-conductive materials are being developed for transparent contact films (TFTs).
- At the Fraunhofer IST a REACH-compliant plastic metallization is used as an alternative to chrome (VI).

Material efficiency

- In a combined process of atmospheric pressure plasma processes and electrochemical processes precious metals are applied to selected areas.
- Working materials with new properties are being found by combining different materials or layer and basic body.

Production efficiency

- Optimized hard-material and nanostructured coating systems for forming or cutting tools increase service lifes and make more economically efficient manufacturing possible.
- Faster to the goal: simulation means ever shorter development times. For example, highly efficient production chains are made possible by model-based design and implementation of coating processes.
- Modules with sensorized thin-film systems are built into deep-drawing systems and driving machines to ensure efficient forming and machining of components.
- Hard carbon-based coatings not only stop materials such as powders from adhering to tools but also prevent deposits on or fouling of surfaces in, for example, heat exchangers or exhaust systems.

Energy efficiency

- Lower energy consumption due to the erosion protection of aero-engines: very hard multilayer coatings of ceramic and metal prevent excessive fuel consumption and falling efficiency levels.
- Broader and improved range of applications for lightweight components by means of wear-resistant, friction-reducing coatings which also protect against corrosion.
- Reduced solar radiation in buildings by the use of electrochromic windows.

Clean environment

- With the diamond electrodes developed at the Fraunhofer IST water can be conditioned electrochemically – adapted to the infrastructure on the spot and without the use of chemicals.
- Photocatalytic coatings make self-disinfecting surfaces possible and the degradation of pollutants from the air.
- The functionalization of surfaces in plasma enables to dispense with adhesive, for example bonding materials. Plasma pretreatment is also suitable as a replacement for primers and as a way of improving the adhesion of paint systems.

Health

- Plasma medicine has a great potential for the sustainable treatment of patients. With the medical device PlasmaDerm®, for example, open wounds can be treated efficiently. In the long term, this accelerates the healing, reduces the time and personnel expenditure and increases the quality of life.
- The use of atmospheric pressure plasmas allows to kill even multiresistant germs.

Mobility in the future

- Low-friction and extremely wear-resistant coatings reduce the fuel consumption of car engines and extend both maintenance intervals and service life.
- New corrosion coatings on metallic bipolar plates make possible the economic production of powerful fuel cells for the automotive industry.
- Robust thin-film sensor systems in highly stressed parts of components increase reliability and safety in many fields of application, such as electromobility.
- Functional coatings for components of lithium ion batteries raise the efficiency and the durability of these storages for electro mobile applications.

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MECHANICAL ENGINEERING, TOOLS AND AUTOMOTIVE TECHNOLOGY

The "Mechanical engineering, tools and automotive technology" business unit is primarily concerned with developing coating systems for friction reduction and also for wear and corrosion protection and optimizing these for particular applications. This covers the entire process, from pretreatment, coating and process development –including analysis and simulation–to application. Pretreatment includes not only cleaning but in particular also adjusting surface topographies by abrasive blasting or plasma processes as well as a diffusion treatment, if necessary. Examples of applications in the components field are:

- DLC and hard coatings for motor and drive components
- Surfaces for batteries and fuel cells in mobile applications
- Non-stick and antifouling coatings
- Surface optimization and corrosion protection of hybrid components
- Metallization and functionalization of plastics
- Highly corrosion-resistant carbon coating systems for sealing applications

Another important activity is the design of coating processes by simulating real 3D components.

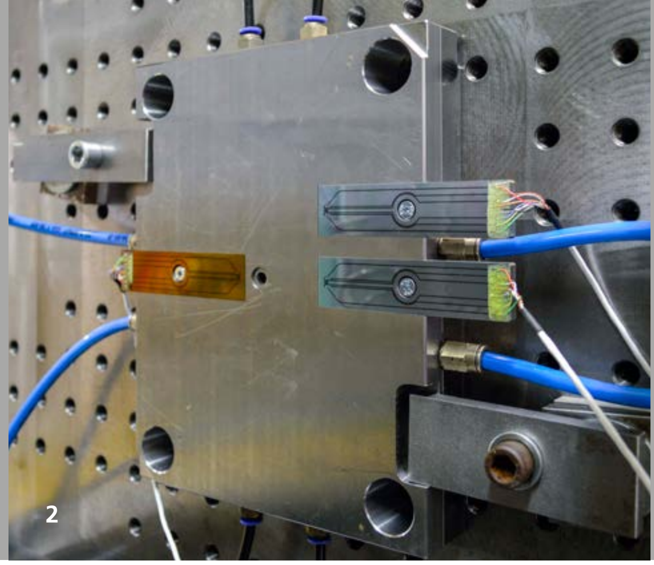
In the mechanical engineering and tools field these areas of application stand in the foreground:

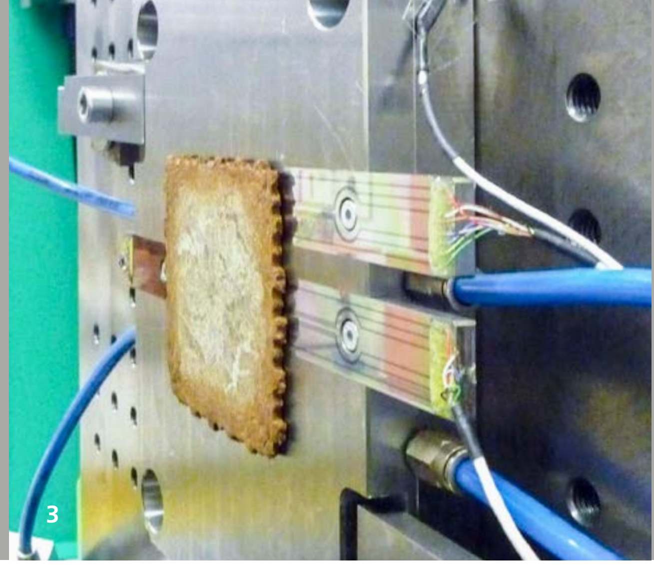
- Coatings for pressure die-casting molds
- Tool coatings for plastic molding (pultrusion, injection molding)
- Plasma diffusion treatment (including thermodynamical simulation) and coating of forging and press-hardening tools

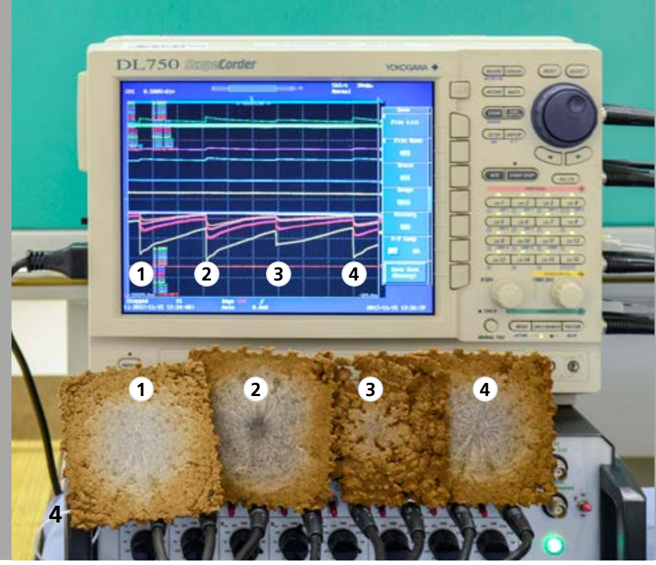
In addition, sensorized surfaces are developed for and successfully used in the most varied safety-related areas of application, such as:

- Sensorized washers for continuous force monitoring
- Pressure and temperature thin film sensor systems for highly stressed tools
- Thin-film strain gauges
- Magnetic functional layers

In addition to coating service providers our customers primarily include companies in the automotive sector, toolmakers, tool users and also coating users in all fields of mechanical engineering.







SENSORS FOR EFFICIENT MANUFACTURING OF NATURAL FIBER REINFORCED PLASTICS

From several perspectives the integration of renewable raw materials in plastics is a very important development objective for our time. From the ecological perspective, an ever-increasing proportion of plastic can be countered with recyclable natural fiber reinforced plastics. From an economic perspective, new material composites are being developed which are of great interest for the automotive industry and the lightweight sector. However, for the production of such natural fiber reinforced plastic parts in injection molding processes, increased wear occurs in the extruder area and in the mold, and this in turn results in shorter tool life, which causes process costs to increase significantly. Consequently, within the Cornet project "Smart NFR" innovative, multi-functional film systems are being developed that reduce wear on the mold and extruder area of the plastic injection molding system. In addition, the process should be optimized through integration of thermo-resistive and piezo-resistive thin-film sensor structures in the coating system developed at the Fraunhofer IST.

Manufacturing of the sensory thin-film system

On steel inserts that can easily be installed in the injection mold, as base layer the piezo-resistive and wear-resistant DiaForce® film is deposited homogeneously in the thickness of 6 µm. On this layer individual chromium electrode structures are placed in such a manner that they are in the contact area of the plastic melt. This is followed by two insulating coatings of alumina or SiCON®, between which the conductive traces from the electrodes to the contacting areas and a temperature sensor in meander geometry are manufactured out of chromium. The entire film system has a thickness of approximately 10 µm. A mold insert with a complete film system, in which alumina as well as an insulating intermediate coating and a top coating have been deposited, is presented in Fig. 1. The two circular areas represent the piezo-resistive sensor areas that are half-enclosed by the meander-shaped structure of the temperature sensor.

Testing of the sensory film systems in the injection molding processing of different natural fiber reinforced plastics

At Tomas Bata University in Zlín, three inserts with sensory thin-film systems were installed in the mold of the injection molding machine of the company Arburg (Allrounder 470 H) and were tested with different natural fiber reinforced plastics. The individual systems have different colorations. This is caused by the different insulation coatings (see Fig. 2): In the case of the left insert SiCON® coatings were deposited as intermediate coating and as top coating. On the other hand, for the two inserts arranged on the right, the transparent alumina was used as a wear-protection insulating coating. Fig. 3 shows an injection molded part after opening the mold, still in contact with the sensor systems. Using the voltage curves of the individual thin-film sensor structures, even during the injection molding process it is possible to detect whether or not a good part has been manufactured (see Fig. 4). So far the thin-film systems for detection have been used in more than 500 injection molding processes with different fiber-reinforced plastics, without showing signs of wear.

Outlook

In the future, the wear-resistance of the various thin-film sensor systems should be investigated for the injection molding of plastics that are reinforced with natural fiber like wood fiber, and reinforced with talc or slate powder. Moreover, sensor inserts should be developed for the extruder area of the injection molding system and their usability should be tested in contact with different natural fiber reinforced plastics.

The project

The results described were achieved within the project "Smart coating systems for process control and increased wear resistance in processing of natural fiber reinforced polymers", or in short "Smart NFR", in which the Fraunhofer IST is working jointly with the Fraunhofer Institute for Machine Tools and Forming Technology IWU and Tomas Bata University in Zlín in the Czech Republic. Smart NFR is funded in the 19th Cornet Call (Collective Research Networking) through the Federal Ministry for Economic Affairs and Energy (BMWi) and the German Federation of Industrial Cooperative Research Associations (Arbeitsgemeinschaft industrieller Forschungsvereinigungen e.V. (AiF), and the project will run from 06/01/2016 to 11/30/2018.

1 *Mold insert with complete sensor system.*

2 *Injection molding machine with three integrated sensory inserts in the mold.*

3 *Wood fiber reinforced injection molded part, still in contact with the sensor systems.*

4 *Comparison of characteristic voltage curves with different stages of the injection molding results. The best-formed wood fiber reinforced component (2nd from left) was produced with the greatest voltage change of all sensor structures.*

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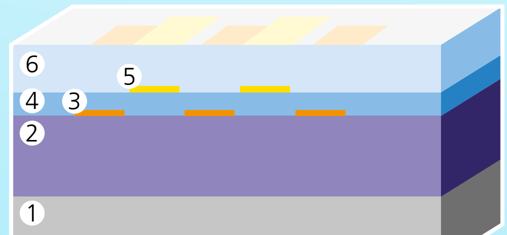

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6. Insulating and wear-protection layer (SiCON®)
5. Temperature meander structure
4. Insulating and wear-protection layer (SiCON®)
3. Electrode structure Cr
2. DiaForce®
1. Steel base body

APPLICATION-SPECIFIC MANUFACTURING OF SENSOR SYSTEMS

The customer request is the focus of sensor developments at the Fraunhofer IST. This involves the geometry of the base body, as well as the type and number of the sensor systems that are combined in a thin-film system. Currently in this regard piezo-resistive and thermo-resistive sensors are available, in which the requirements of the client are appropriately implemented. Several examples are presented in Fig. 1 and Fig. 2.

The manufacturing of the sensory thin-film system

In most cases they are manufactured out of hardened steel and in shape they are reminiscent of washer geometries, which can easily be used to monitor threaded connections. For this, initially with the aid of a PACVD process, a DiaForce® film that was specially developed at the Fraunhofer ST, is deposited. Then individual circular electrode structures are manufactured out of chromium, and these structures form the load measuring sensor surfaces (see Fig. 1 and Fig. 2). Then on a subsequent, electrically-isolating SiCON® intermediate layer, a hydrocarbon coating modified with silicon and oxygen, which likewise is deposited in the PACVD process, conductive traces are structured to contacting points, as well as temperature-measuring meander structures out of chromium. These structures are protected against wear with a second and final SiCON® layer (see Fig. 3).

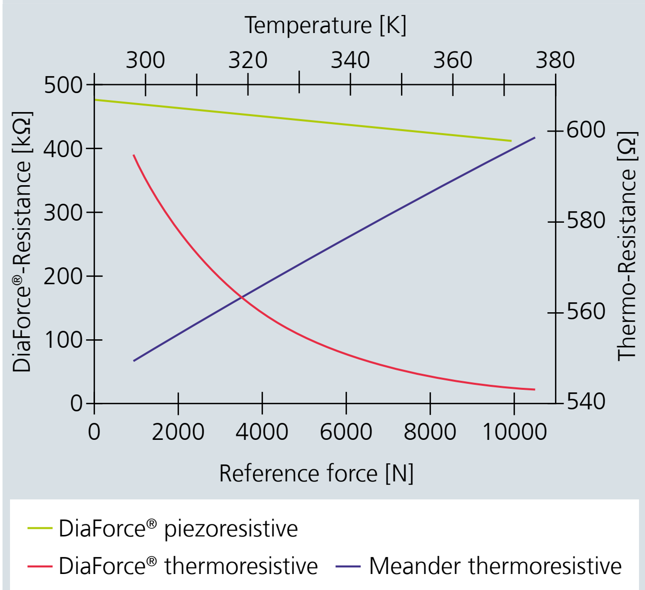
Sensor characteristics

In test stands of the Fraunhofer IST the temperature-dependent and load-dependent characteristic curves of each individual sensor structure are measured. In the case of piezo-resistive sensors these are characteristic linear resistance dependencies on the load. In this process a full-bridge or half-bridge circuit is established and a constant voltage of 5 V is applied. The thermo-resistive meander structures likewise show linear resistance dependencies. They are structured in a so-called four-wire arrangement; via the outer conductors a constant current of 10 mA, for example, is applied and the voltage change is measured via the inner conductors. Due to the fact that the piezo-resistive DiaForce® sensor film, as an amorphous carbohydrate film, is a semiconductor it has an exponential resistance dependency on temperature. This effect can be compensated through the additional integration of temperature-compensating structures in the contacting area. Sample characteristic curves of a force sensor structure and of a temperature meander are presented in the adjacent diagram.

Outlook

In accordance with customer requirements, in the future this should be further developed into sensor systems with wireless data transfer. On the other hand, first and foremost the tasks on the multi-functional film system should be pursued with regard to improved and new sensor integrations.

Load-dependent and temperature-dependent resistance curve of a sensor structure and the linear resistance dependency on the temperature of a meander structure.



1 *Washer-like sensor systems with different sensor arrangements on the surface of a hardened steel substrate.*

2 *Sensor systems with additional wear protection coating (on the right, partially deposited).*

3 *Schematic presentation of the coating system.*

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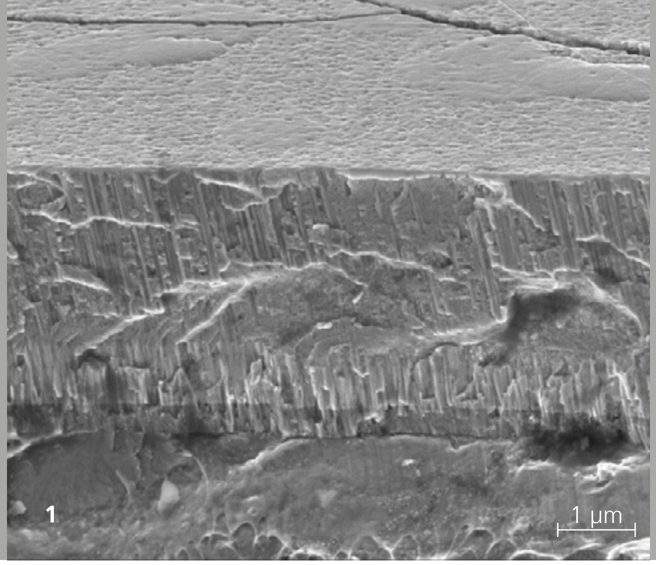
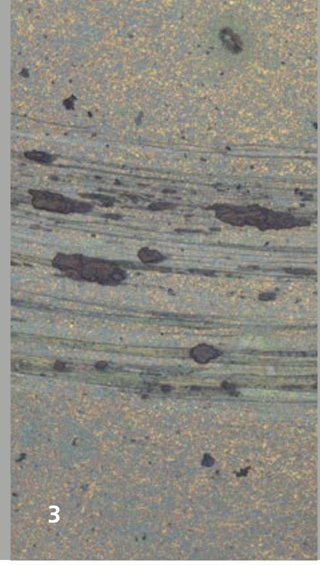
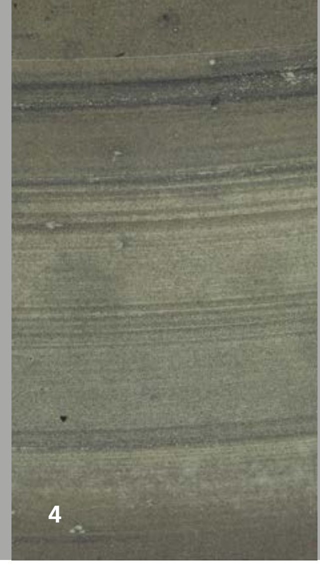






FORMING TITANIUM ALLOYS EFFICIENTLY

Currently efficient technical forming processes, such as deep-drawing or hydroforming, can only be used for titanium alloys with severe restrictions. The high adhesion tendency of titanium alloys results in rapid tool wear when forming in the temperature range from 500 °C to 950 °C. Even when using temperature-resistant lubricants, the surface quality of the component and the process stability of the forming operations no longer meet the requirements after a short time. Consequently, the Fraunhofer IST develops anti-adhesive tool coatings for high-temperature forming of titanium funded by the Federal Ministry for Economic Affairs and Energy, with these coatings more efficient forming processes and an improved component quality should be achieved in the future.

Titanium alloys

Titanium alloys are characterized by a favorable ratio between weight and strength, good ductility, high thermal resilience, corrosion resistance, and biocompatibility. If used as a base material there is significant potential for development in a wide variety of application areas, such as aerospace, the chemical industry, and medical technology, as well as shipping.

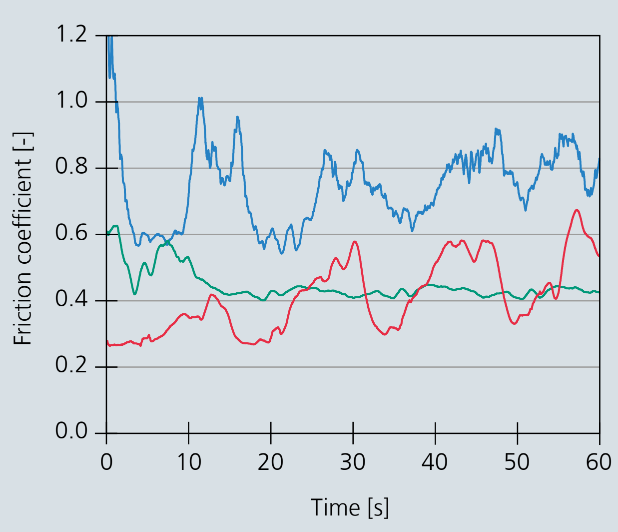
Layer development

The tungsten carbide tool coatings developed at the Fraunhofer IST (see Fig. 1) follow the principle for providing a self-lubricating boundary layer during the forming process. Application-oriented laboratory tests (see Fig. 2) prove that this effect causes a significant reduction in tool wear and of the associated friction forces in the contact with adhesive titanium materials (see Fig. 3 and the adjacent graphic). Other long-term tests substantiate a uniform layer performance even for stress durations in the range of industrial applications. These findings indicate that cost-intensive lubricants can be dispensed with and tool life and component quality can be increased. In addition to all major tool steels, temperature- resistant nickel-based materials can be coated with the aid of the PVD technology used. Depending on the tool material selected, operating temperatures of up to 950 °C can be achieved in different atmospheres, such as air, argon, or nitrogen.

Industrial application

Layer development occurred on PVD magnetron sputtering units in accordance with the industrial standard. Thus, the developed coatings can directly be transferred on real forming tools and used for industrial forming processes. The first real forming tests for solid forming and superplastic sheet metal forming of high-strength titanium alloys are currently being conducted with the project partners and should constitute the basis for final qualification of the film systems developed for industrial application.

Modifications of Inconel718 as tool material in comparison: Tribometer tests versus TiAl6V4 at 950 °C in Ar protective gas atmosphere.



1 *SEM micrograph of the developed tungsten-carbide based tool coating.*

2 *High-temperature tribometer with optional protective gas atmosphere for application-oriented layer development.*

3-4 *Wear characteristics after application tests versus TiAl6V4 at 950°C under protective gas atmosphere. (3) Uncoated, with adhesion of titanium. (4) Coated, without any adhesion.*

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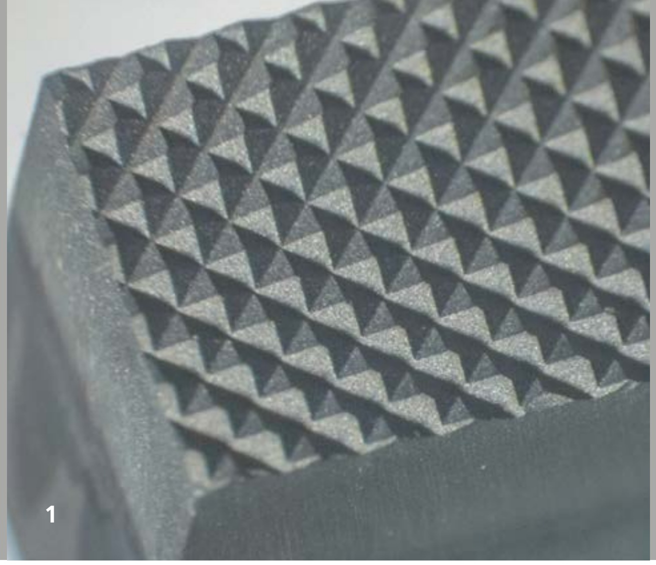
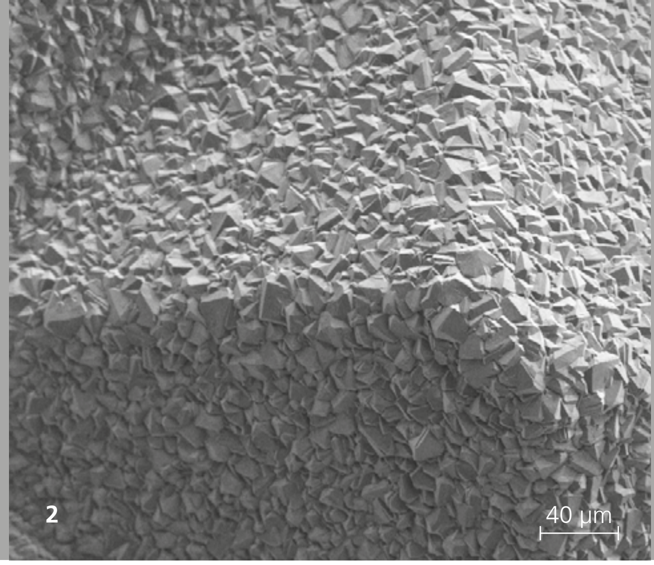
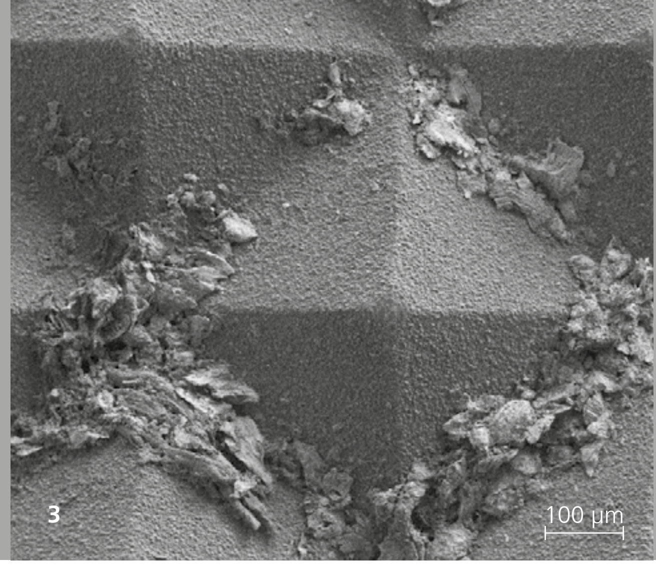
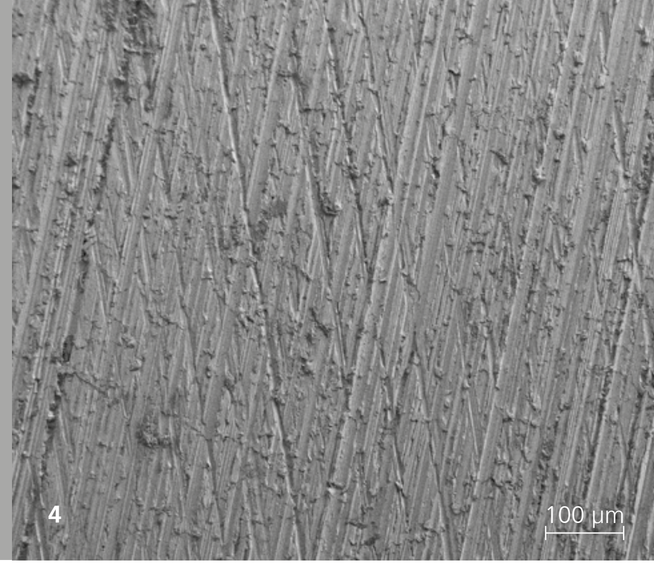








TEXTURED CVD DIAMOND HONING STONES

Cylindrical crankshafts of combustion engines are honed in the final machining stage. In this process honing stones are pressed against the surface and moved with a combined rotary and lift motion. Thus, the internal cylinder surface is machined and the typical crosshatch honing grooves are created, which are necessary for the tribological characteristics in contact with the piston ring as counter-body. In a funded project at the Fraunhofer IST in cooperation with the Institute for Machine Tools and Production Engineering (Institut für Werkzeugmaschinen und Fertigungstechnik IWF) of the Braunschweig University of Technology, innovative CVD diamond honing stones have being developed and successfully tested, which show several advantages relative to conventional honing stones.

The solution approach

Honing stones that have been hitherto used consist of bonded diamond grains. The disadvantage in this regard is that in most cases a three to four-stage process chain is necessary to achieve the desired result. Moreover, a comparatively large amount of lubricant is required. On the other hand these newly-developed honing stones have a combination of geometrically-defined cutting edges – the pyramid structure (see Fig. 1) – and geometrically-undefined cutting edges – the crystal tips of the microcrystalline CVD diamond film (see Fig. 2). Thus, significantly greater freedom is obtained in the design of the tool and thus in the characteristic of the surface topography of the processed material. Where applicable this permits shortening of the process chain and it also means that lubricants can be dispensed with to a great extent or even completely.

The results

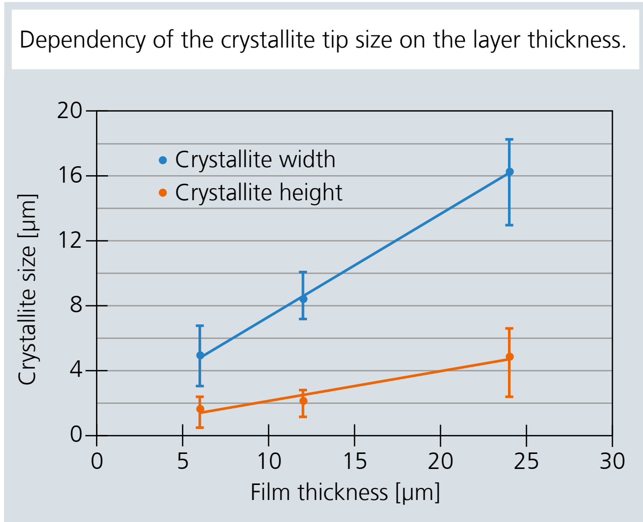
In the first step, the manufacturing technology for grinding various pyramid textures in the base body of the ceramic honing stone was developed at the IWF. In parallel, at the Fraunhofer IST scientists worked on a coating technology for precisely-contouring and highly-adhesive CVD diamond thin-films that are 12 to 24 µm in thickness and have variable crystallite sizes (see adjacent graphic). The prototype tools were tested at the IWF by honing gray cast iron and a thermal sprayed ferrous coating. It was shown that machining via external cylindrical honing, as well as internal cylindrical honing, was easily possible. In a long-term test over 17 hours only minimal wear occurred without the end of service life having been reached. There was no chip congestion or clogging; the chips remaining in the texture valleys (see Fig. 3) could be easily removed. In addition, with an identical honing pattern the same material removal rate and workpiece roughness (Fig. 4) were achieved as with conventional honing stones. Furthermore, with the new tools, for the first time it was possible to hone material with minimum quantity lubrication and even a complete dry honing process was possible.

Outlook

In the future the very successful work on this innovative tool concept will be carried forward. In this regard, among other things, the objective is to generate additional honing stone textures and to test their influence on the honing patterns of the workpiece. Moreover, manufacturing effort should be further reduced in order to make the new tool concept more economical.

The project

The IGF project 18682 N of the Deutsche Gesellschaft für Galvano- und Oberflächentechnik e. V. – DGO, Itterpark 4, 40724 Hilden was funded via the AiF within the framework of the program for promoting Industrielle Gemeinschaftsforschung (IGF) of the Federal Ministry for Economic Affairs and Energy by decision of the German Bundestag.



1 *Innovative textured honing stone of silicon nitride ceramic, coated with CVD diamond.*

2 *SEM micrograph of an apex of a pyramid, layer thickness 24 µm.*

3 *SEM micrograph of the hone tool surface after honing gray cast iron.*

4 *SEM micrograph of the honed gray cast-iron surface.*

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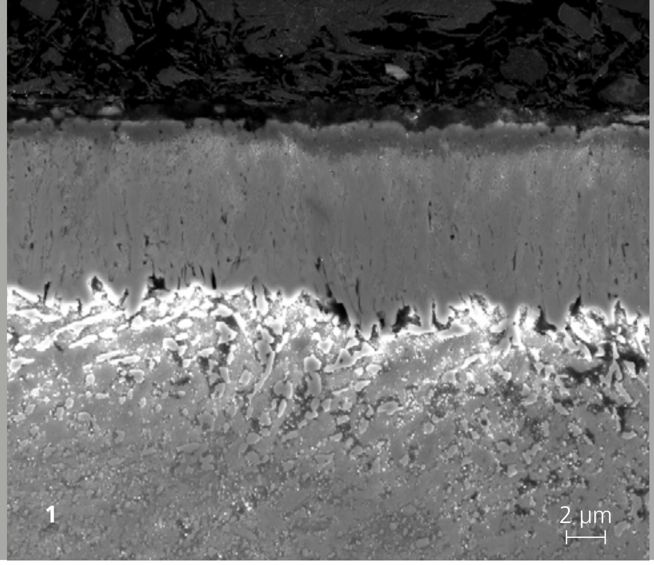

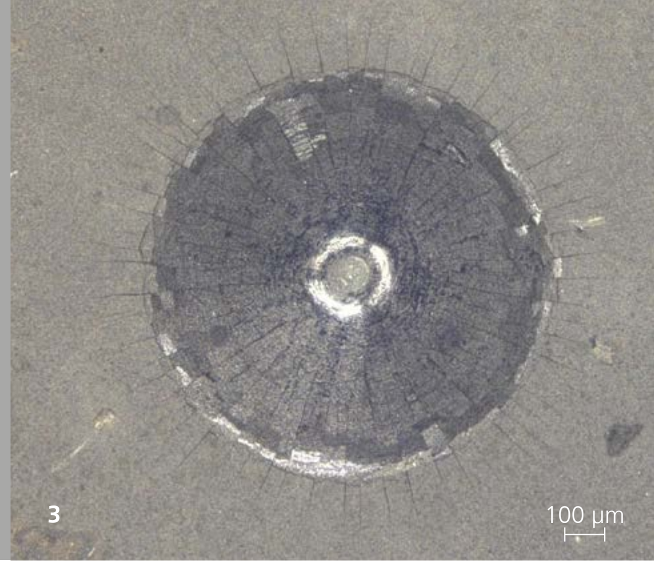

GAS BORIDING OF HIGH ALLOY TOOL STEELS

Gas boriding of tool steels is an entirely new approach for the wear protection of molds and forming dies. Through newly developed processes at the Fraunhofer IST now high alloy tool steels can also be effectively handled with this process.

Boriding of steel materials

The boriding of low alloy steels has been known for many years. In this process boride is diffused from a powdery or pasty donor medium into the tool surface at temperatures above 750 °C. Subsequent vacuum heat treatment restores the initial hardness of the base material. Boride layers form that are very hard and very resistant with a greater layer density than is the case with conventional hard material films. A disadvantage of this process is that residues of the donor media are left on the material surface and must be removed and subsequently disposed of with extensive effort. To avoid these disadvantages, possibilities are being investigated for working with harmless gaseous donor media. To a great extent this has already been done successfully through an additional plasma support for the boriding of low alloy steels. However in this area, at this point in time the formation of pores was a problem. Moreover, the technology was not suitable for treatment of high alloy steels.

The new boriding process

At the Fraunhofer IST specialists have succeeded in producing virtually pore-free boride films on different high alloy hot-working steels and high-speed steels at temperatures from 700 to 750 °C in a vacuum chamber through a modified process gas implementation and optimized gas distribution. In this process BCl_3 was used as the donor medium. An additional plasma support is not necessary. Another advantage of the new boriding process is that the required use of the donor medium has been reduced by more than half.

The layer properties

With the new process after a process time of just two hours a layer thicknesses of more than 10 µm could be achieved. Depending on the tool steel used and the process parameters the layer hardness's are between 1800 and 2500 HV. In tribometer tests in a so-called ball-target arrangement the layers show excellent friction and wear behavior against steel and aluminum balls. Also, noteworthy is the extremely low adhesion tendency relative to aluminum.

Outlook

As part of the IGF project "Use of plasma boriding processes to increase the resilience of forging dies" (IGF 19553 N) currently the use characteristics of the boride layers are being investigated in series forging trials. Additional application tests for forging and casting of aluminum as well as sheet-metal forming of steel and light alloys are in preparation.

The project

The IGF project, IGF 19553 N of the Research Association for Tools and Materials (Forschungsgemeinschaft Werkzeuge und Werkstoffe e. V.) has been funded via the AIF as part of the program for promoting industrial collective research (IGF) from the Federal Ministry for Economic Affairs and Energy based on a resolution of the German Bundestag

1 Boriding layer in high alloy thermal hot-working steel 1.2343.

2 Experimental tool for hot forging applications.

3 Rockwell impression in a 10 µm thick boride layer.

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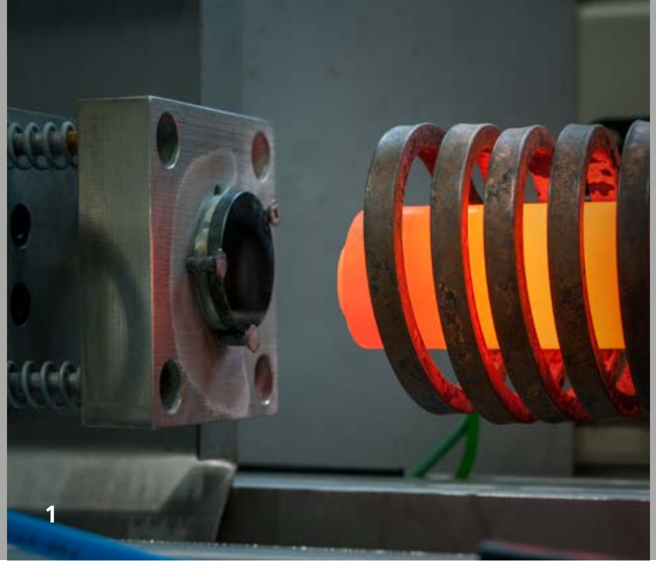
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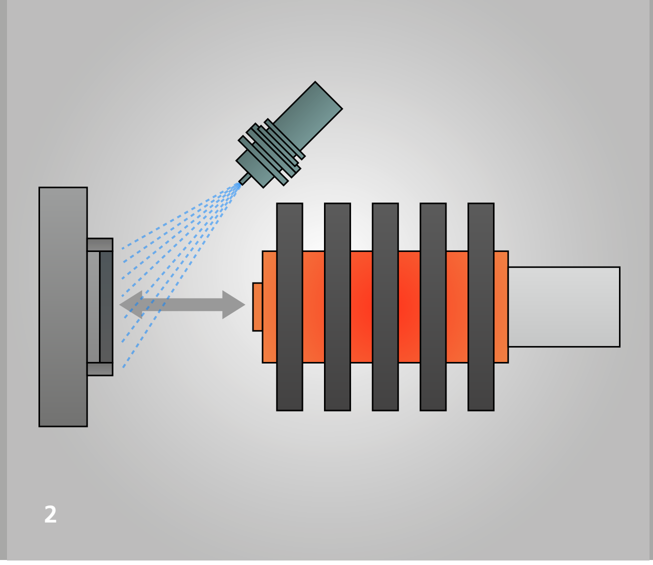
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THERMAL SHOCK TESTERS FOR LIGHT METAL CASTING AND FORGING TOOLS

Minimization of wear on tools is a key criterion for economical series production, in particular for light metal casting and forging. Thermal shock loads frequently result in thermal shock cracks that are a major cause of failure of these tools. However, tool life can be increased through suitable edge layer treatments, such as diffusion treatments (nitriding, boriding) or coatings. A suitable testing technology is indispensable for evaluation of the edge layers with regard to their resistance to thermal shock. Consequently an innovative thermal shock test stand has been developed at Fraunhofer IST.

The thermal shock test stand

Simple test methods for the film and material testing with a variety of adjustable parameters are of crucial importance for an economical tool design. The thermal shock test stand developed at the Fraunhofer IST relies on the specific failure mechanisms of light metal castings and forged tools. Thus, with the thermal shock tester many scenarios of real tools in laboratory scale can be simulated. This means that a cost-effective and temporally attractive pre-characterization of materials and edge layer treatments is possible prior to the actual coating of the series production tools.

The functional principle

Via a high-performance induction coil a punch is heated up to maximum 1000 °C. The sample to be examined moves cyclically against the heated-up punch with an individually adjustable holding period. After the reverse movement of the sample it is quenched with a sprayed-on cooling medium at a defined cool-down rate. In order to simulate the temperature curve on a series production tool as precisely as possible, the temperatures on the sample and on the punch are recorded. The adjacent graphic shows a sample temperature curve.

The possibilities

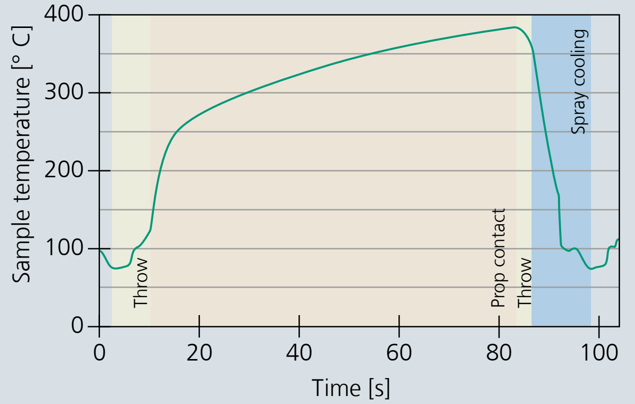
Through the varied possibilities offered by the test stand a high level of flexibility is provided for a wide variety of applications. Thus it is possible to precisely adjust the essential parameters, such as contact time and punch temperature, and through this to work with different spray cooling concepts. Among other things, in this regard different spray parameters such as cone shape, pressure, direction, and duration can be changed. Moreover, the sample temperature has an essential influence on the spray cooling concept. With spray cooling under 300 °C the surface of the sample is completely moistened and cools off quickly. With vaporization cooling above the so-called Leidenfrost temperature of 450 °C, the liquid vaporizes completely when it hits the sample and the cooling effect is reduced.

For the most part the test stand works in an automated procedure, so that even extensive test cycles can be implemented. After the test cycle the effects on the samples, such as scale formation, corrosion of the surface, crack formation, annealing effects, or changes in the grain boundaries can be characterized in detail.

The advantages

Minimization of wear on tools for light metal casting and forging is of central significance for the industry. Frequently these tools are quite costly, so that testing of new tool materials and edge layer treatments in production constitutes an extremely high risk. Consequently, the possibilities for extending the service life of tools are not often used. The test stand offers the alternative of enabling pre-series tests with realistic stresses.

Heat-up and cool-down curve of the sample in the thermal shock test stand.



1 *Glowing punch with sample in the thermal shock test stand.*

2 *Schematic setup of the test stand.*

3 *Microscopic image of a tool surface with signs of wear.*

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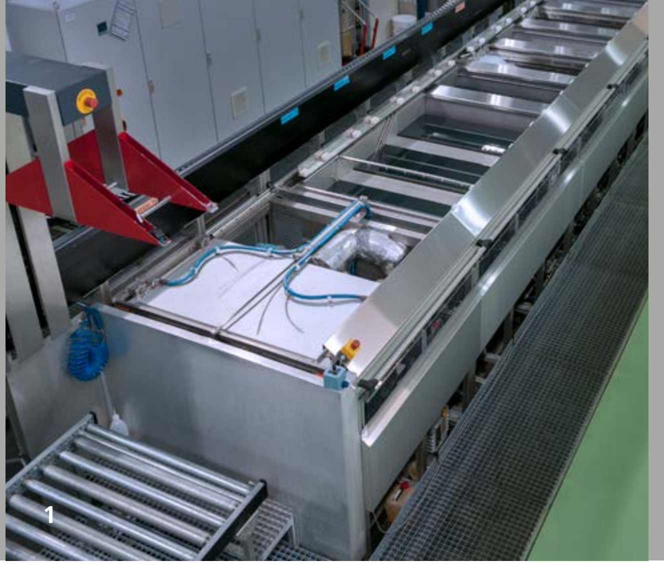

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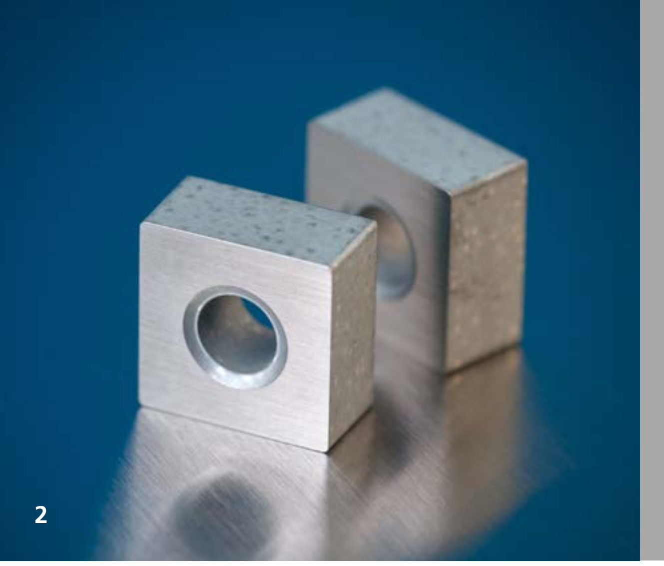

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3

PROCESS CHAIN FOR THE PRETREATMENT OF TOOLS FOR PLASMA COATING

The application properties of hard material coatings on geometrically complex cutting tools directly depend on the surface cleanliness of the cemented carbide substrate surface before coating. To increase the environmental compatibility of an optimized cleaning process chain consisting of treatment steps with a subsequent fine plasma cleaning directly before coating, the Fraunhofer IST has developed a new process chain for the pretreatment of tools and evaluates this process chain relating to the application with industrial partners.

Cleaning process chain

In the manufacturing route, cemented carbide cutting tools pass a quite complex process, consisting of grinding and polishing steps that produce resistant residues on the surface, due to the process heat that occurs within these steps. For the most part these residues are still virtually impossible to detect after the final cleaning in production, even with a light-optical microscope. Nevertheless, they exert a negative effect on the integration, i.e. adhesion of the hard coatings. To increase the process reliability of the coating processes, the Fraunhofer IST combined the following ecological cleaning approaches and subsequently investigated their technological load-bearing capacity by means of service-life analysis:

- Aqueous cleaning with biodegradable cleaners
- CO_2 snow blasting for residue-free cleaning
- Plasma-electrolytic polishing with environmentally-compatible media
- Plasma supported cleaning under vacuum conditions with innovative generator concepts

Aqueous cleaning

The 15-chamber cleaning system available at the Fraunhofer IST is used as the reference equipment for a water based cleaning technique that is appropriate for the coating adhesion (see Fig. 1). The system is configured precisely for the needs of the IST, as a variety of substrate materials and substrate geometries – from flat substrates to complex tools – can be cleaned. Moreover, the applied cleaning media can flexibly be adapted to the cleaning task. A sophisticated bath monitoring and recipe control coupled with an expert system enable reproducible pretreatment processes. The system qualifies innovative, biologically safe, and degradable cleaners that are used efficiently with additional support in their cleaning effect via ultrasonic enhancement. The formulation of the special cleaning chemistry occurs on the basis of renewable and/or biologically degradable raw materials, such as tensides and/or other surface-active substances, such as glycosides.

Plasma supported cleaning

In the final step of the pretreatment all chemical compounds down to the nanometer scale are removed from the substrate surface under vacuum conditions via plasma-chemical and plasma-physical processes, and the substrate surface is chemically activated. This plays an essential role for the adhesion of subsequently applied coatings. Key factors are the distinct plasma conditions, which are modified in broad ranges through variation of the pulse geometry and acceleration tensions.

Evaluation

To verify the effectiveness of the newly developed cleaning process chain, a developed synthetic contamination is initially applied and afterwards removed from the sample component surfaces. These synthetic contaminants simulate the manufacturing process as precisely as possible or impose additional requirements on the process, through representation of massive film or particle coatings. Then in a second step, complex cutting geometries, such as drill or milling tools, are provided with wear protection coatings. Finally machining tests prove service live times that are required technologically as well as economically.

Industrial uses

The improved pretreatment process chain enables hard coatings with uniform quality. Moreover, the new procedure is far more cost-effective than classic wet-chemical or solvent-based process chains. On one hand, cost savings can be achieved through simultaneous reduction of the process residues in the cleaning procedure, on the other hand due to the intelligent linking of modern and more environmentally-friendly cleaning processes, significantly lower disposal costs and energy costs are incurred.

1 Multi-chamber system at the Fraunhofer IST for aqueous cleaning with high reproducibility and flexibility in materials to be cleaned.

2-3 Testing tools used for the development of the cleaning procedure: (2) Cemented carbide inserts as references for simple geometrical requirements. (3) Drilling tools with high geometric requirements imposed on the cleaning process to be developed.

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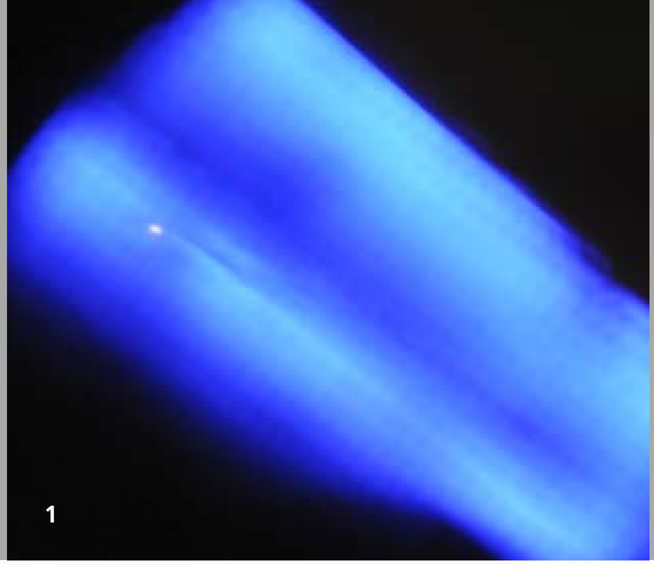

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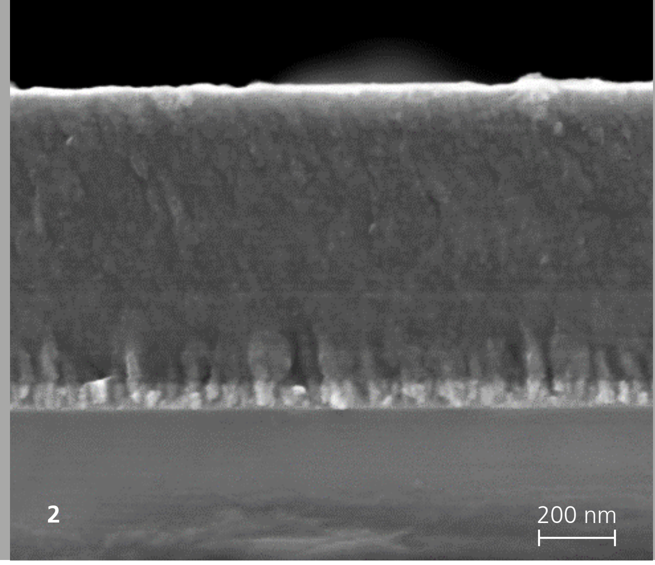


2

HIPIMS-ARC MIXED MODE DEPOSITION OF ta-C FILMS

Diamond-like carbon (DLC) films make an essential contribution towards eliminating friction in a variety of applications. Particularly in the area of mobility fuel consumption, and accordingly CO_2 emissions can be reduced through the use of DLC films. In this area, the hydrogen-free hard DLC films, so-called ta-C films are very popular. Currently these films are almost exclusively manufactured by arc evaporation. At the Fraunhofer IST work is currently underway on an alternative manufacturing method: combined HIPIMS-Arc mixed mode deposition.

The conventional arc process
With the conventional arc process the raw material, carbon, is ionized. The additional energy of the ions ensures extremely high hardness of the deposited films. However due to the process droplets and defects are also generated that can result in rough surfaces and thus render cost-intensive rework of the surface necessary. Alternatively, filtered arc processes can also be used, which induce fewer film defects, but at the same time show a significantly lower deposition rate than the unfiltered processes.

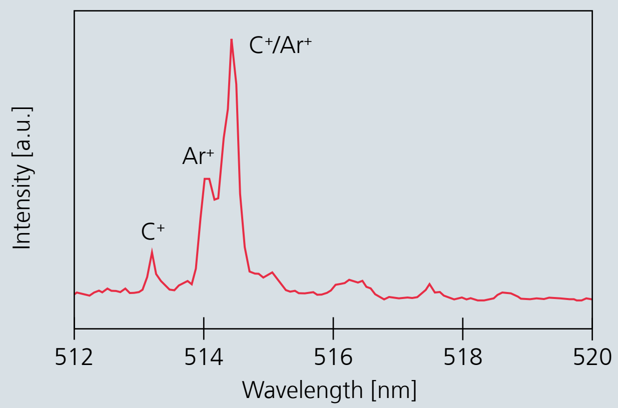
Generation of carbon ions for production of smooth, super-hard films
High Power Impulse Magnetron Sputtering (HIPIMS) is a lower-defect alternative to the arc process. In 2010 [M. Lattemann et al. Diam. Rel Mat. 20 (2010) 68–74] a new variant of the highly-ionized process was introduced, in which the HIPIMS discharge was systematically transitioned into an arc discharge. In a 2015 publication [R. Ganesan et al. J. Appl. Phys. 48 (2015) 442001] for lab scale systems using a round target with a diameter of 7.5 cm, a proportion of over 80 percent of diamond-bonded compounds, so-called sp^3 is reported. The objective of the work conducted at the Fraunhofer IST was to implement a HIPIMS-Arc process in an industrial coating system using cathodes with 600 cm^2 target surface area and a length of approximately 0.5 m (see Fig. 1).

Reproducible adjustment of the ARC transition in the HIPIMS deposition
At the Fraunhofer IST, a HIPIMS generator with peak current of 2000 A was used for the HIPIMS-Arc process. It was possible to successfully define work points at which the continuous HIPIMS discharge is reproducibly transitioned into an arc discharge. The pulse length, the selected working pressure, and the charging voltage of the generator are particularly significant in this regard. The fabricated optical emission spectra prove that in the arc events carbon ions are generated that substantially influence the film growth (see adjacent graphic).

Deposition of ta-C films
After evaluation of the boundary conditions for the systematic transition of the discharge into an arc and verification of the existence of carbon ions, films were deposited for the mechanical characterization. Films with a thickness of up to 2 µm were produced for the investigation. These coatings showed hardness levels of up to 3500 HV (see Fig. 2). It was possible to significantly reduce the defect density and size of the defects as compared to arc films.

Outlook
Currently work is underway to further optimize the process. The defects should be further reduced or completely eliminated and the hardness should be further increased. In particular for components that cannot be retroactively processed, even at this point the process offers an attractive alternative for a film with smooth ta-C layers.

Temporally integrated optical emission spectrum with carbon ion emission lines of the ionized carbon and argon.



1 *Arc event during the HIPIMS discharge.*

2 *Scanning electron micrograph of the fracture edge of a ta-C film with a hardness of 3500 HV.*

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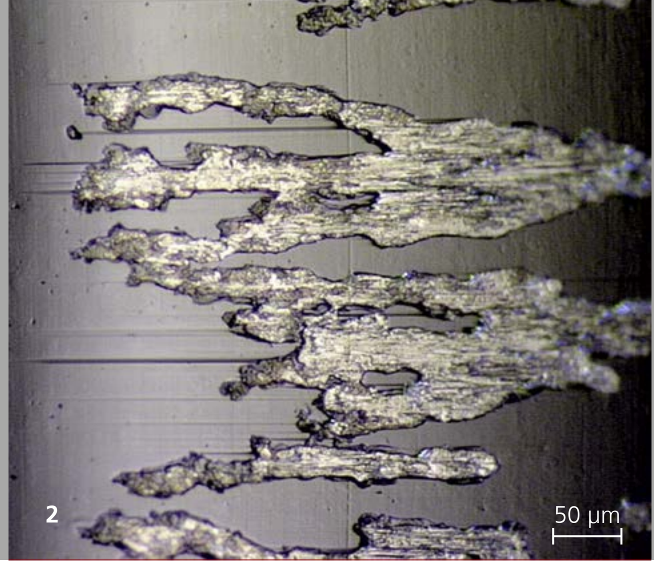

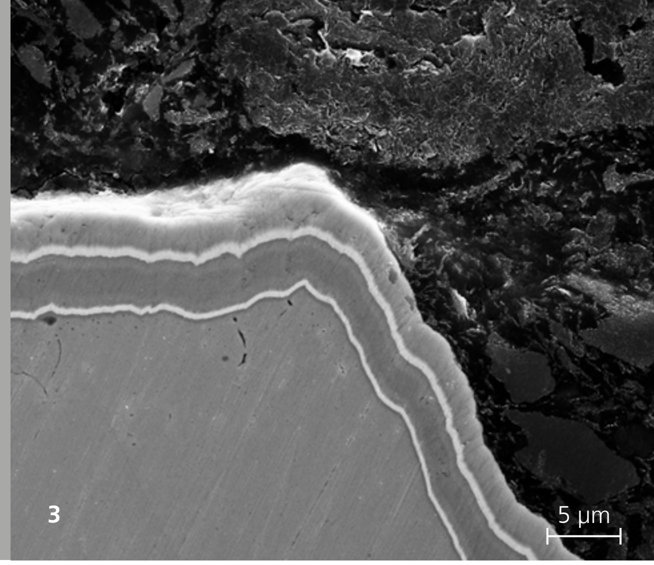

DLC COATINGS FOR FORMING

Coatings of amorphous hydrocarbons (a-C:H), also known as diamond-like carbon coatings, (DLC) are outstandingly suited for the low-lubricant forming of metals, and here due to their low adhesion tendency, in particular for the forming of aluminum. However, due to their incredible hardness and minimal layer thickness, they are also more susceptible to damage. In the AiF Cornet project "Development of DLC-based duplex coatings for highly loaded forming tools" at the Fraunhofer IST a combination of nitriding and DLC coating is used to increase the resistance of the DLC coatings, particularly on tools. In this regard, particular emphasis is placed on adapting the procedure to tools with a complex shape. The project is undertaken in cooperation with the Centre de Recherches Métallurgiques in Belgium.

Resistant but demanding – DLC coatings on tools

With hardness of up to approx. 2000 HV, DLC coatings offer significantly higher resistance against abrasive wear than does hardened tool steel (approx. 800 HV). The low coefficient of friction of approx. 0.1 – unlubricated under standard conditions against steel – in addition enables use in friction pairings that are either minimally lubricated or not lubricated at all. However the incredible hardness also makes them more susceptible to damage prone to the so-called eggshell effect. This means that local overloads result in excessive punctiform tension stress of the coating and of the underlying material. The consequence is a collapse of the maximum 5 µm thick DLC coating into what is usually the significantly softer base material.

For the coating of tools the existing radii and edges pose a special challenge, since the quality of the precipitating coatings is considerably influenced by the geometry. Under real implementation conditions rarely do the nominal load conditions pose the greatest challenge in ideal operation. But rather it is the irregularities in operation, such as misalignment or contamination that generate the cited punctiform loads and thus cause fatal coating damage.

Support effect through case hardening

One possibility of avoiding the coating damage is to intensify the support effect of the steel material underneath the coating through case hardening, for example. Therefore, in the project described the tool surface was plasma-nitrided prior to actual coating, and thus resistance to plastic deformation was increased. At a thickness of up to 1 mm, the edge zone of the steel hardened in this manner to 1400 HV, reduces susceptibility to the eggshell effect. This result is a significant improvement of coating adhesion and the resistance to punctiform-overload on all steels. Different test methods, such as the scratch test or an impact endurance test, confirmed the results.

In the further course of the project the steels most frequently used in forming tools were systematically tested for their suitability and the specific needs for this process. Their specific compositions and morphological properties essentially determine the nitriding result and the behavior of the coating under load.

Outlook

In collaboration with the companies in the project-accompanying committee and the Belgian cooperation partner, in the forthcoming phase of the project the results should be transferred to tools in industrial use. In this regard the tools made available with adapted combination processes will be treated and tested under real implementation conditions. First and foremost the complex application situations often require a high level of stressability, particularly in the function areas of the tools. Moreover the complex shapes of their surfaces pose a technical coating challenge, since curved surfaces, radii, edges, and depressions influence the nitriding and coating results.

1 *Forming processes (here: clinching) subject tools to high stresses.*

2 *Local peak loads result in spalling of the coating.*

3 *Precision nitriding and coating on contours is a basic prerequisite for tools that can withstand high stresses.*

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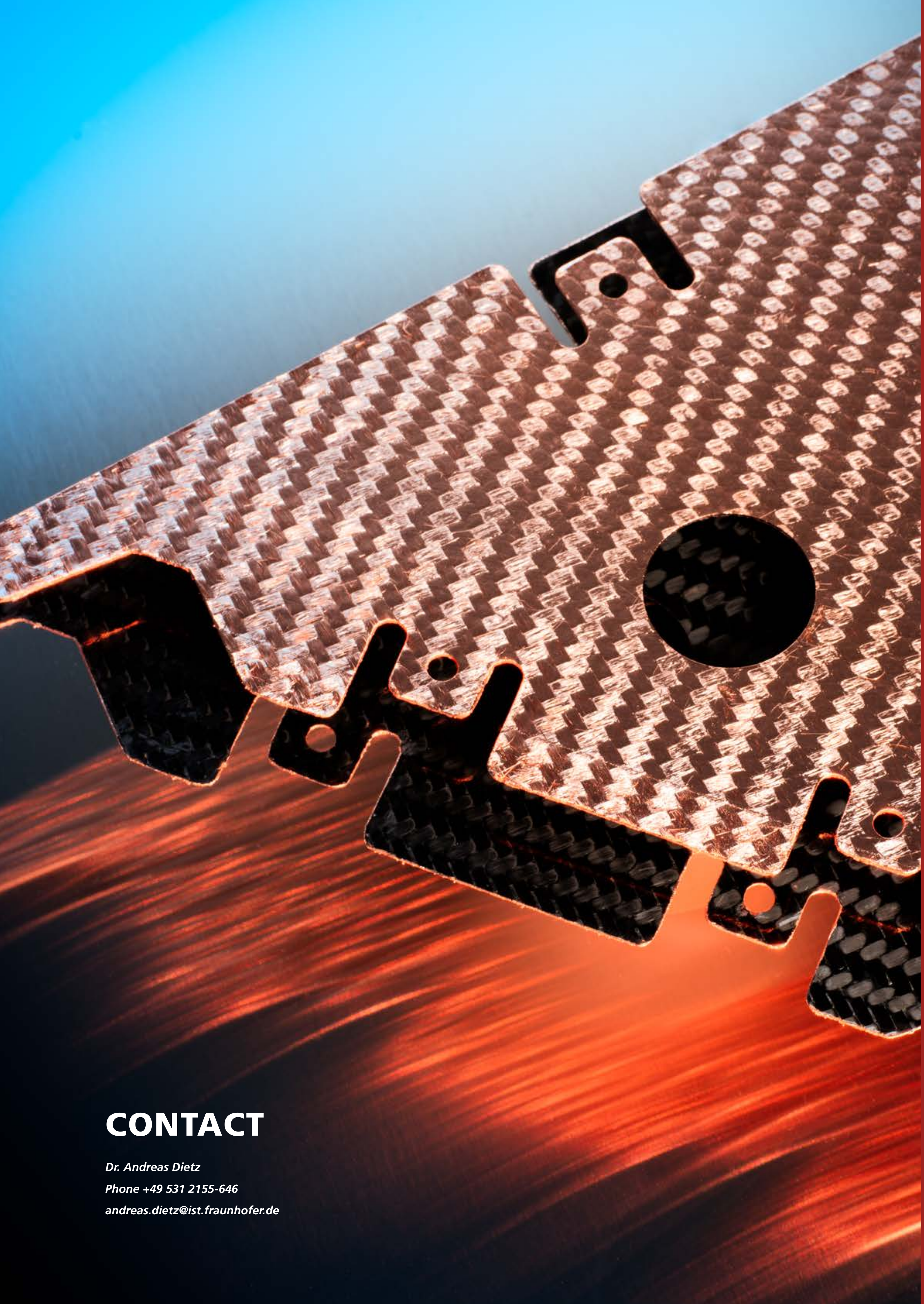

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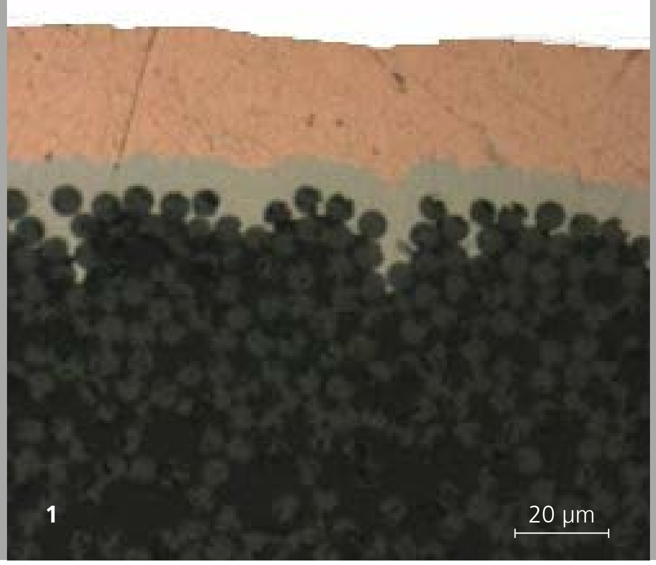
AEROSPACE

In this business unit, coating technologies are developed for the aerospace sector. The focus is on functionalizing lightweight materials such as carbon fiber reinforced plastics (CFRP) or light metals. In addition, coating systems are developed for optical applications, in particular for special precision filters for space missions.

Currently the Fraunhofer IST is working on the following projects:

- Electroplated metallization of CFRP components
- Development of new environment-friendly CFRP metallization methods
- Surface treatment of light metals e. g. titanium, magnesium, aluminium
- Wear-protection coatings for engines in jet aircraft
- Bearing sensor systems for condition monitoring in aircraft
- Development of surfaces for molds free from release agents
- Development of coating processes for precision lenses such as filters

Customers include companies from the aerospace sector as well as their suppliers.



METALLIZED CFRP MIRRORS FOR OUTER SPACE

Optical mirrors for space applications must have extraordinary stability due to the constantly changing thermal stresses in outer space, but also due to the high mechanical stresses at lift-off of a rocket. For this reason, as rule optical mirrors are manufactured of metals, ceramics, or glasses. These materials have a high specific weight and are the cause of tremendous costs at start. Consequently, at the Fraunhofer IST work is underway on a significantly lighter alternative: Mirrors of carbon fiber reinforced plastic.

CFRP – a lightweight

Carbon fiber reinforced plastic (CFRP) is a real champion among lightweight materials. With a specific weight of 1.6 g/cm^3 it is even lighter than aluminum, magnesium or titanium, and in addition it has significantly better mechanical characteristics. For this reason it is used wherever weight reduction is essential. What is new however is the use of CFRP material as mirrors for space applications. A comparison makes this clear: A mirror segment of beryllium that is used in the James Webb Space Telescope has a mass of approximately 20 kg. A comparable metallized mirror of CFRP has a mass of approximately 3.5 kg.

The manufacturing of the metallized mirror

In the project "OCULUS" (Optical Coatings for Ultra Light-weight Robust Spacecraft Structures) funded by the German Aerospace Center (DLR) the Fraunhofer IST develops a folding mirror of CFRP in collaboration with the Technical University of Braunschweig and the company INVENT GmbH. This mirror will be metallized and surface-treated in a subsequent step. In a process developed at Fraunhofer IPT, so-called ultra precision turning, the initially quite rough and irregular surface is processed to a mirror finish.

The metallization of CFRP was developed at the Fraunhofer IST where the process has been successfully used for approximately 10 years. Well-known application examples include the CFRP antennas that are used in space flight. However, in the specific case of the CFRP mirror, additional requirements are imposed on the base material: It must not deform, even under the changing temperatures in outer space conditions, and in addition it must meet the optical requirements. To do this, the base material is modified. A modified layer of nickel approximately 200 µm thick that must be absolutely free of pores is used as the coating. This layer is then again turned to a minimal layer thickness in a downstream process. In this process the unevenness is leveled and a roughness of approximately 5 nm r_a is achieved.

Outlook

Due to the significant weight savings, metallized CFRP surfaces with optical application offer significant potential. Further developments must improve the reliability of the metal deposition. Moreover, modifications of the CFRP material are also necessary in order to stabilize the material even under changing temperature conditions. In addition to space travel, implementations in other business sectors are also conceivable, e. g. in the machine tool industry and in the automotive industry.

1 Micrograph of the metallized CFRP sample.

2 Machine for ultra-precise turning of surfaces.

3 Coated and ultra-precise turned CFRP mirror.

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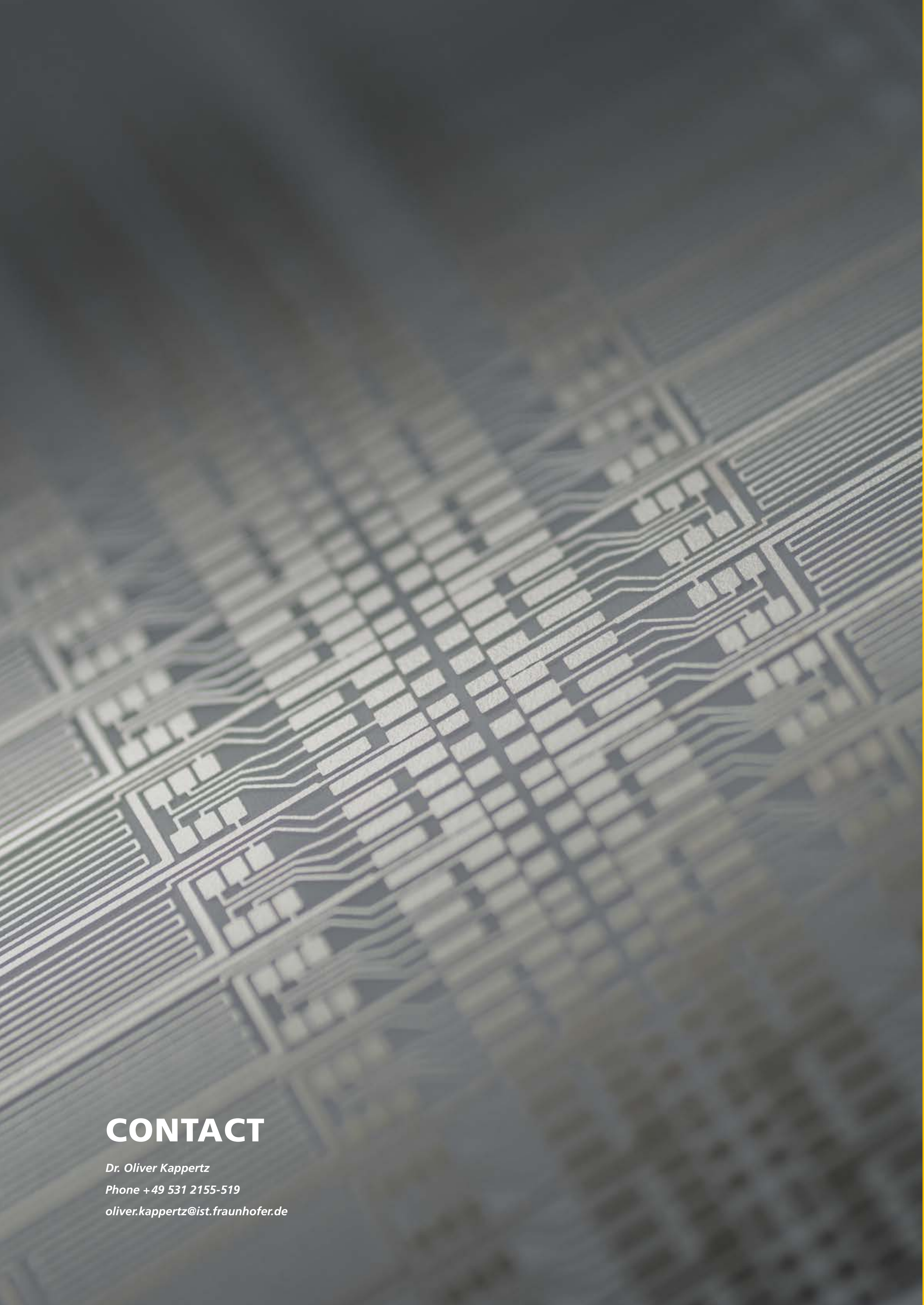

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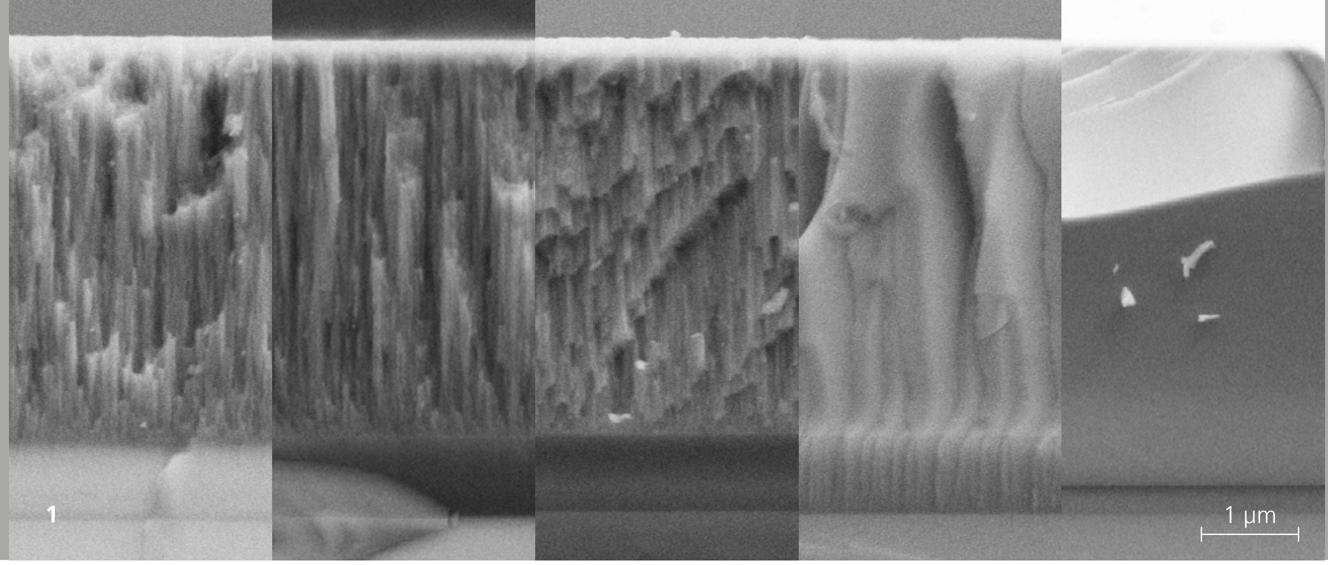
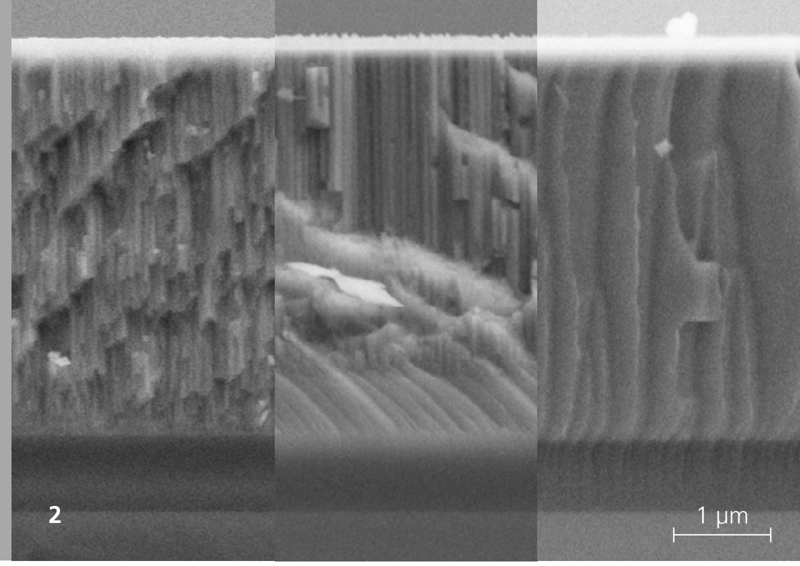
ENERGY AND ELECTRONICS

In the "Energy and electronics" business unit the work of the institute concentrates on the following developments:

- Functional coatings or coating systems and coating processes for architectural glass (low-E coatings, active or passive heat and sun protection, switchable electrochromic glazing)
- Transparent conductive coating systems (TCOs) for architectural and automotive glazing, for solar cells, displays and invisible heating elements and also for solar thermal energy
- p- and n-type TCOs as materials for transparent and flexible electronics
- Semiconductor layers for thin film and silicon-based photovoltaics and also characterization methods for thin-film solar cells
- Electrical contact and insulating layers, as well as barrier layers
- (Local) plasma treatment of surfaces for wafer bonding, structured metallization and metallization of temperature-sensitive and complexly shaped substrates
- Stable anodes and cathodes for lithium-ion batteries
- Electrolytic coatings for high-temperature fuel cells (SOFC) and gas separation membranes for hydrogen production
- Corrosion-protection and thermal-barrier coatings for high-temperature applications, such as in gas turbines

Our customers include companies in the glass, photovoltaics and automotive industries, in semiconductors and microelectronics, in the information and communications sectors, in the energy and construction industries, and also plant manufacturers and contract coating companies.





GAS FLOW SPUTTERED SILICON LAYERS

For decades pure silicon has been the main element of microelectronics and therefore has significant technological and economic importance. In current projects researchers are attempting to extend microelectronics with systems that interact with the environment. For example these can be sensory, actuating, chemical, or electrochemical components. In this area as well silicon is an extremely attractive source material, however the traditional deposition processes for semiconductor silicon, such as chemical vapor deposition (CVD), are not always suitable in this regard. As part of a Fraunhofer-internal research program, a new generation of silicon deposition processes is being developed and investigated. One of these processes uses the hollow cathode gas flow sputtering (GFS) developed at Fraunhofer IST.

Gas flow sputtered silicon layers

Gas flow sputtering (GFS) is a high rate sputtering process in which an intensive hollow cathode glow discharge is used for atomization. The atomized species are transported to the component via a directed gas flow. In the research project cited above, highly-doped silicon (n-type, phosphorus) is atomized in a plasma discharge and deposited on level silicon substrates at moderate temperatures. As a representative of physical vapor deposition (PVD) gas flow sputtering uses non-toxic starting materials, and through plasma support, enables an outstanding layer adhesion on the substrate. For deposition, process parameters can be selected in such a manner that the layers either have a columnar, i. e. porous, microstructure or a compact, i. e. dense, microstructure (see Fig. 1). In addition to the structure, the inherent stresses of the occurring layers can be controlled to a certain extent. Typical layer thicknesses here are on the order of 10 µm. However, in principle GFS layer thicknesses of 100 µm and more can be achieved.

Silicon PVD with hydrogen added

Plasma-supported PVD processes are based on purely physical procedures and as a rule use argon as the process gas. On the other hand, in chemical gas vapor deposition (CVD) processes that are conventionally used for silicon deposition, chemical processes are used for mobilization of the particles and layer formation. Often hydrogen plays a decisive role in this regard. However, Fig. 2 shows that hydrogen can also influence the layer properties in PVD processes. Different quantities of hydrogen were added to the gas flow sputtering process in what otherwise were the same conditions. Here the addition of hydrogen increases the mobility of the layer-forming particles on the surface and thus favors a compact layer structure.

Outlook

In the future silicon layers produced with PVD processes could even be bonded lightly in the same process with metallic electrode layers or passivated with barrier layers, such as silicon oxide. The variable microstructure also makes GFS silicon attractive as an anode material for lithium ion batteries, or for catalytically active surfaces, e. g. for gas sensors.

1 *Scanning electron micrograph of silicon fracture edges. Depending on process parameters silicon layers can be generated with a microstructure that varies in porosity or density. In the figure, the substrate bias voltage increases from left to right.*

2 *The density of the forming layers can also be influenced through an addition of hydrogen in the gas flow sputtering process. In the figure the addition of hydrogen increases from left to right.*

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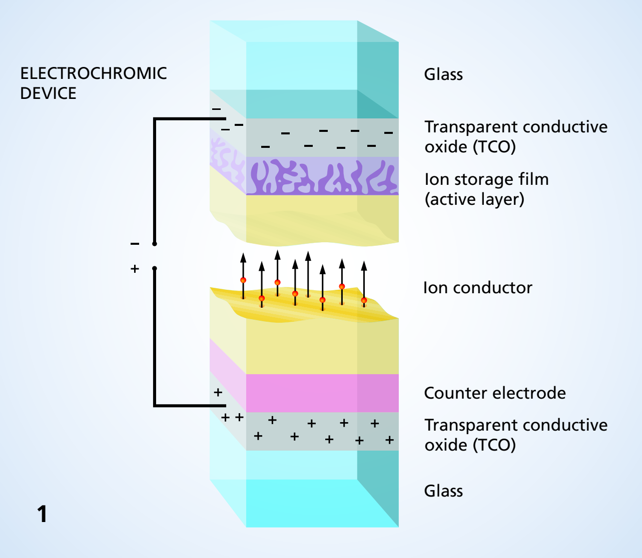


NEW MATERIALS FOR SWITCHABLE GLAZING

The demand for switchable glazing that regulates light transmission and the transmission of energy is increasing for reasons associated with comfort and rising energy costs. This demand primarily involves the glazing for buildings and automotive glazing for the roofs of automobiles. The electrochromic coatings needed for these types of systems are being developed at the Fraunhofer IST.

The principle

The principle structure of an electrochromic film system is shown in Fig. 1. It essentially corresponds to the principle structure of a lithium-ion battery, however with transparent electrodes and an active coating, as well as counter-electrode materials that change their light transmission properties depending on the charge state. As a rule, the active coating consists of tungsten oxide (WO_3). Lithium is stored in this coating when a negative voltage is applied. It then turns dark. This process is referred to as cathodic switching behavior. By switching the polarity of the voltage, the lithium from the active coating is transferred to the counter-electrode via the electrolyte and stored there. This brightens up the active coating.

Ideally, the counter-electrode shows an opposite anodic switching behavior, i. e. a brightening at lithium storage and a darkening in the status without lithium. Such an anodic switching behavior is known for only a few oxides of the transition metals, examples are chromium (Cr), cobalt (Co), manganese (Mn), nickel (Ni), vanadium (V), iridium (Ir), iron (Fe), and ruthenium (Ru). In this regard iridium and ruthenium are not considered for large-surface use for financial reasons. Thus iridium oxide (IrO_2) is only used on small surfaces in switchable auto mirrors. Other boundary conditions that must be considered for use are the achievable light/dark switch states, cycle stability, color impression and the health aspects of the materials.

Innovating counter-electrodes

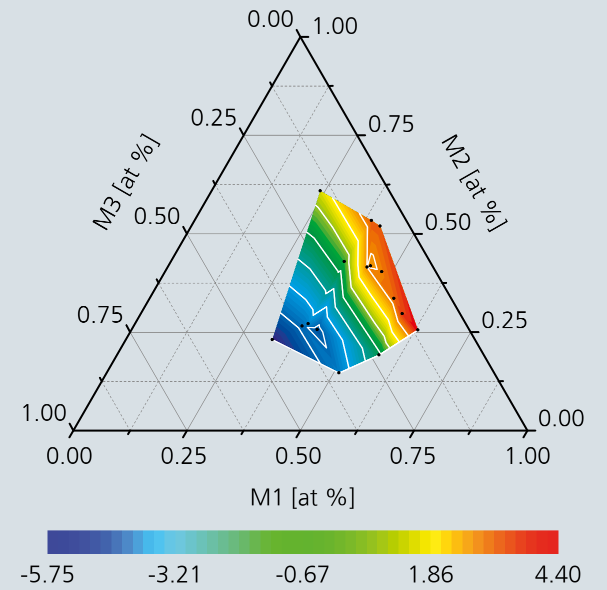
Currently at the Fraunhofer IST, as part of the joint project "Smart Windows of the 2nd Generation 'ECWin2.0'" a new generation of counter-electrodes is being developed jointly with project partners EControl-Glas GmbH & Co and GFE Fremat GmbH. The objective is to modify the existing counter-electrode – a metal1-metal2 oxide – provided from the project partner EControl by adding the elements cited above, and thus in particular further improve the switching behavior and the current slightly yellow color impression.

To do this at the Fraunhofer IST new mixed oxides are being produced via reactive co-sputtering of up to three sputtering sources. The lithium absorption capacity is evaluated by means of cyclic voltammetry. In parallel the visual transmission and its change are measured. After the initial orienting depositions of the pure oxides, e. g. metal1-oxide (see Fig. 2) a wide variety of mixtures were realized. In this regard the most successful shows the desired anodic switch behavior over areas. The optical density (OD) decreases at lithium incorporation (see the opposite graph, $\Delta OD < 0$), i. e. the coating brightens up. The coatings show a concurrent capacity to adequately absorb lithium.

Outlook

Currently the most successful mixed oxides are being investigated relative to their cycling stability and in the composite with the active coating. Moreover, tests on a larger surface in a pilot scale of 30x40 cm^2 are planned.

Change in the optical density (ΔOD) depending on the composition of the metallic components of the counter-electrode.



1 *The principle structure of an electrochromic film system.*

2 *Counter-electrode of metal1-oxide on glass with transparent electrode.*

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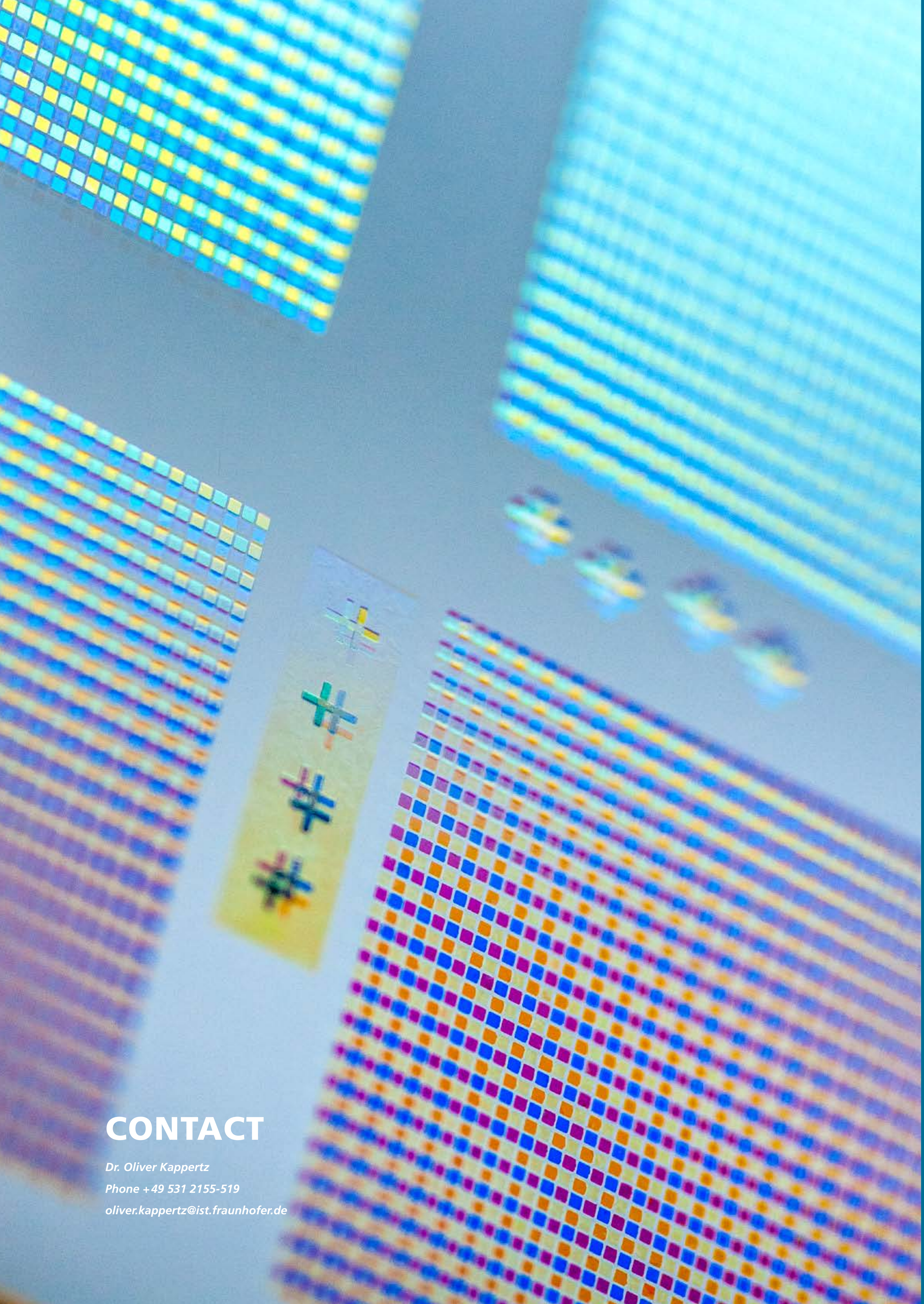

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OPTICS

In its "Optics" business unit the Fraunhofer IST is active with a variety of thin-film technologies in developing new solutions for new industrial applications. These include:

- The development and manufacture of coatings for optical components
- Systems for the deposition of high-grade optical coatings on flat and curved lenses
- The EOSS® production platform for manufacturing optical filters and laser components
- The development of new materials for intelligent coatings, such as electrically switchable filters
- Highly durable broadband anti-reflective coatings on sapphire and glass
- Micro-structured optical filter coatings for imaging applications
- Optical coatings on plastic surfaces
- Use of simulation in designing and optimizing coating processes and installations in low-pressure systems
- Development of innovative transparent conductive coatings for lighting technology and oxide electronics

In the field optical metrology the Fraunhofer IST focuses on the following topics:

- In-situ monitoring of coating processes with MOCCA®
- Mapping system for measurement of ellipsometry, reflection, transmission, flare and Raman spectroscopy on 60 x 60 cm^2
- Defect analysis of optical layers by means of FIB REM and confocal optical microscopy
- Testing the wear and corrosion resistance of optical surfaces and coatings

Clients of this business unit include companies in the optical industry, the automotive industry, aerospace, manufacturers of displays and data storage media as well as plant manufacturers and contract coating companies.

DEFECT-FREE SILICON OXIDE FILMS FOR THE AVOGADRO PROJECT

The prototype kilogram to which all scales are calibrated is losing weight. Consequently, in an international project the basic unit of mass will be redefined and in the future based on natural constants. To do this, in the so-called Avogadro experiment scientists will determine how many atoms are contained in virtually perfect silicon spheres. At the Fraunhofer IST film processes will be executed for homogeneous and uniform silicon oxide film (SiO_2) of the sphere surface to reduce the degree of measurement uncertainty.

Redetermination of the Avogadro constant

The kilogram is the last unit of measure in the international measurement system that is defined through a macroscopic body – the prototype kilogram. All other units are already based on atomic processes, molecular properties or natural constants. If scientists succeed in counting the number of atoms in a silicon crystal with the mass of 1 kg with the utmost precision, then in the future the material kilogram can also be replaced through a physical constant.

The Avogadro constant is being worked on in a worldwide project. In this regard, several metrological institutes are conducting the individual measurements: From determination of the mass of the sphere, the volume of the sphere or the molar mass via analysis of the lattice parameters and density differentials, and extending to investigations of oxide layer properties, water layer and impurities.

ALD-SiO_2 minimizes measurement uncertainties

There is always a natural layer SiO_2 on the surface of the silicon spheres, which likewise has an influence on mass and volume. This native layer grows slowly, however to some extent it also grows quite unevenly. This means that the actual weight of the oxide layer and the actual weight of the sphere are very difficult to measure. Consequently, to redetermine the Avogadro constant an alternative, homogeneous SiO_2 film is being investigated to reduce measurement uncertainties and to enable precise determination of volume and mass of the sphere.

With the aid of the atomic layer deposition (ALD) available at the Fraunhofer IST, stoichiometric SiO_2 films can be deposited with a defined roughness and adjustable layer thickness; the condition of these films satisfies the rigorous requirements: They are reproducible and can be applied as an extremely thin oxide layer with homogeneous thickness on the sphere. Potential impurities, such as carbon or nitrogen, are below the detection limits, the roughness of the films remains under one nanometer.

The deposition processes of the silicon spheres were performed in 2017. The results within the Avogadro consortium will be presented in 2018 at the Conference for Weights and Measures. By this time at the latest the prototype kilogram will be replaced as the standard. At the Fraunhofer IST, at the end of 2017 additional films of silicon spheres took place to investigate the influence of different SiO_2 layer thicknesses.

Outlook

The SiO_2 films developed at the Fraunhofer IST do not only enable application on spherical systems, but rather on any complex structured services desired. Thus, the possible future areas of implementation are varied and extend from optical applications to the semiconductor and electronics sector and to medical technology.

1 *A look into the silicon sphere.*

2 *Preparation and holding arrangement of the silicon sphere for the coating process .*

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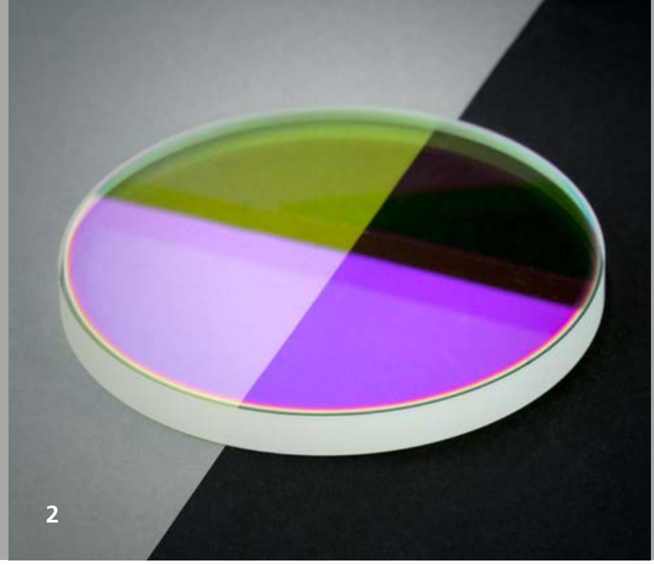


DEVELOPMENT OF AN OPTICAL BEAM SPLITTER WITH AN EXTREMELY STEEP EDGE

At the Fraunhofer IST outstanding possibilities for the deposition of highly demanding optical coatings were provided with the EOSS® (Enhanced Optical Sputtering System) coating platform. Thus not only can coatings with a very low defect rate be produced, but highly-complex coating designs can also be mapped with extreme precision and uniformity of the coating. With rotatable cathodes, optimized sputter targets, and use of the magnetron sputtering technology the system enables production of optical filter coatings with excellent coating quality that are required for many industrial applications. One example is an optical beamsplitter with an extremely steep edge, which was developed at the Fraunhofer IST as part of the BMBF project.

Project objective

Development of the extremely steep edge filter, which allows realizing a high throughput laser direct imaging (LDI) system, occurred as part of the project "Entwicklung eines hochintegrierten digitalen Hochleistungsbelichters für die Belichtung von Lötstopplacken" (Development of a highly-integrated digital high-performance laser direct imaging system), abbreviated as: DAHLIA. The objective was to generate a coherent laser beam in a very narrow spectral range, and thus generate a significantly increased laser output (see adjacent Fig.). However, in the case of LDI imaging for printed circuit boards (PCB), for physical-chemical reasons only a limited spectral range can be used to generate wavelengths of 400 nm. Consequently, in this example laser diodes with wavelengths between 395 and 405 nm were used.

The principle of edge filters

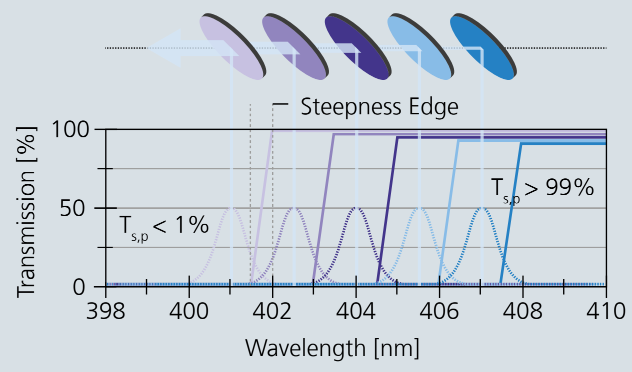
Edge filters, which are also referred to as beamsplitters, are produced through dielectric multi-layer coating. In this process a low-index and a high-index material are stacked on top of each other as a thin film, so that ultimately a spectral range of higher reflection, as well as higher transmission, occurs. Since under ideal conditions an absorption is not present, this means high transmission as well as minimal reflection, and vice versa. The edge, i.e. the transition area between high reflection and high transmission, becomes steeper as more layers are used. The steeper the edge, the closer the filters can be placed side-by-side, and the more laser diodes that can be coupled without loss (see adjacent Fig.).

Manufacturing the edge filters

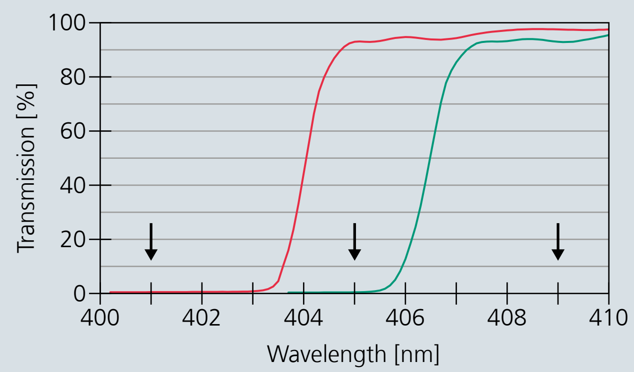
In this project this resulted in film systems with more than 100 individual coatings in some cases, and an overall film thickness of more than 15 µm. The individual layers must be produced with extraordinary precision, as even least coating fluctuations would mean poorer overall performance. Consequently, for the manufacturing of the filters the EOSS® coating system was used, with which in addition to high precision, low-scatter coatings can also be produced. Because the light passes through multiple coated optics, and thus losses due to scatter would be multiplied the low-scatter coatings are especially important.

The adjacent diagram shows the spectra of several manufactured filters. It is clear that an excellent edge steepness has been reached. Smaller drops in the transmission are caused by remaining layer thickness fluctuations, however these fluctuations are currently being further optimized. However, the previously produced filters already fulfill the desired function requirements in an outstanding manner.

Principle of the spectral overlay by means of edge filters. The dotted lines represent the emission lines of the laser diodes; the edges of the different filters are shown as solid lines.



Presentation of various edge filters. The arrows mark the wavelengths of the laser diodes.



1 *Black coating with dielectric beamsplitter film for use in outer space applications, e.g. in spectrometers.*

2 *Example of a dielectric beamsplitter consisting of approx. 100 individual layers with a reflection in the range of 750–850 nm and a transparency in the range of 450–745 nm.*

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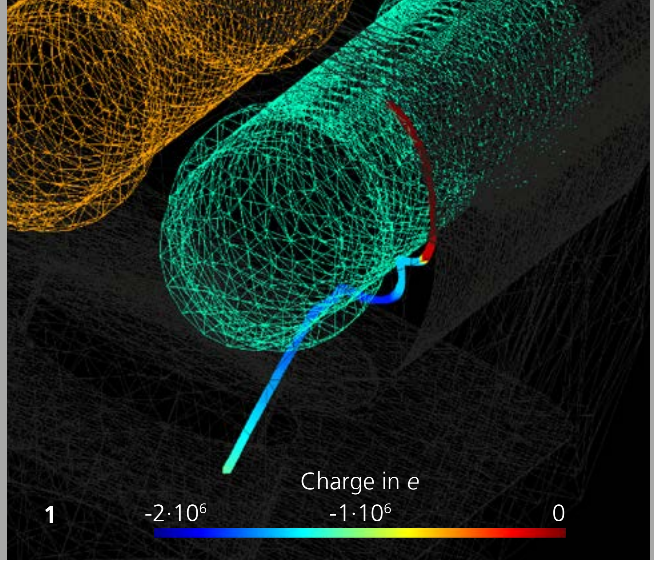

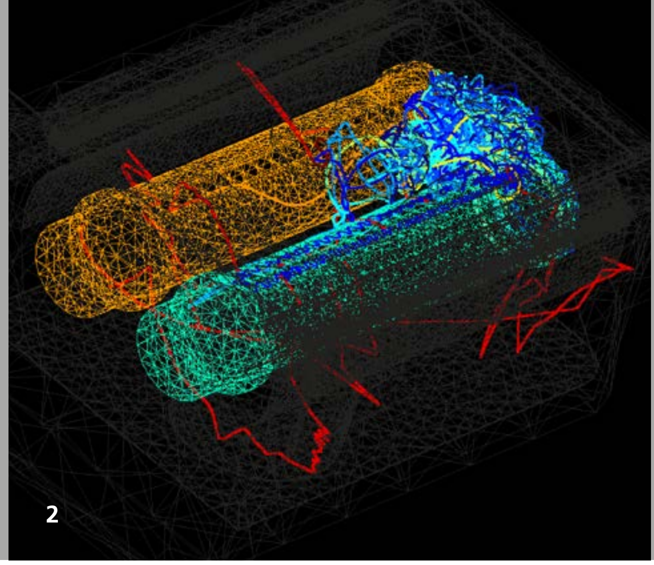

SIMULATION OF DUST PARTICLE MOVEMENT IN A PLASMA

For optical applications it is necessary to generate surfaces that are as pure as possible. Even the smallest degree contamination can reduce or even completely destroy the effectiveness of the entire layer. Dust is a particular challenge for optical applications because the technical effort necessary for its total avoidance in coating systems increases markedly as the desired degree of purity increases. Via a particle simulation developed at the Fraunhofer IST it is now possible to predict the contamination of dust in plasma coating systems. Thus, an important contribution is made towards minimizing the number of defects in the course of subsequent optimization of coating processes.

The solution approach

Dust cannot be completely avoided, consequently one strategy to minimize the number of defects is to tolerate the dust, but keep it away from the surfaces. To do this a good understanding of the behavior of dust in the plasma of a coating system is necessary. However, this is made more difficult through a large number of phenomena resulting from the interaction between plasma and dust. To understand and predict all influences in sufficiently good approximation it is useful to execute simulations in this regard. For this purpose a special program has been developed at the Fraunhofer IST for the simulation of dust particles.

The implementation

The dust particles in the simulation are modelled in a simplified form as homogeneous spheres, which can carry either a positive or a negative charge. They are located in a virtual system, whose geometry is comprised of triangular surfaces, and the particles are generated at random points on the geometry.

The characteristic parameters of the plasma, such as density, temperature, and flow velocity are obtained from separate plasma simulations, likewise developed at the Fraunhofer IST. From these parameters ultimately the surface currents and forces on the dust particles can be calculated, from which a dynamic change in the charge, as well as the velocity and thus the location of the particles results. This is executed at regular time intervals, through which the precision of the simulation can be controlled. Relevant effects on dust particles are:

- The direct drag through neutral gas and plasma
- The repulsion and attraction of the electrostatic potentials between charged dust and ions
- The tendency of the particles to follow heat flows

Macroscopic forces, such as gravitation and electromagnetism are likewise taken into account in the simulation, as well as the interaction of dust with surfaces through reflection or absorption of the particles.

Utilization of the results

If the simulation is run with a variety of start points for different particle types, then locations can be identified at which statistically a particularly high number of dust particles gathers, or from which a high number of particles emanate. Individual strategies for effective avoidance of contamination can be derived from this simulation, these strategies in turn can be optimized through additional simulations.

Outlook

By using the program for dust particle simulation it could be possible to generate optical coatings that are significantly more precise and pure. The precision can even be further increased by supplementing additional forces and influences, so that the processes that are responsible for the dust load can be better investigated. An extension of the concept to other application areas with plasmas is likewise conceivable.

1 *Simulation of a microparticle in the EOSS® system with the charge represented in color.*

2 *Simulation of ten nanoparticles, likewise in the EOSS® system.*

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LIFE SCIENCE AND ECOLOGY

In the field of "Life science" the Fraunhofer IST develops coatings, processes and equipment for a range of application fields:

Cell culture technology and microbiology

- Control of cell adhesion and differentiation
- Control of protein adsorption
- Coupling of antibodies
- Cell transfection and transporation

Medical technology

- Microfluidics
- Biosensors
- Lab-on-a-chip
- Internal coating of tubes, bottles and bags
- Functionalization of the surfaces of disposable articles
- Implants

Medicine and hygiene

- Dentistry
- Sterilization of surfaces and disinfection

In the field of "Ecology" the Fraunhofer IST focuses on the following topics:

- Water disinfection and wastewater treatment by means of diamond electrodes
- Photocatalytic air and water purification systems
- Self-cleaning and antifouling
- Standardized test procedures for the neutral evaluation of photocatalytic properties of products
- Halogen-free flame protection for textiles

In addition to users in the fields mentioned, our customers also include manufacturers of equipment for surface modification and coating as well as contract coating companies at home and abroad.


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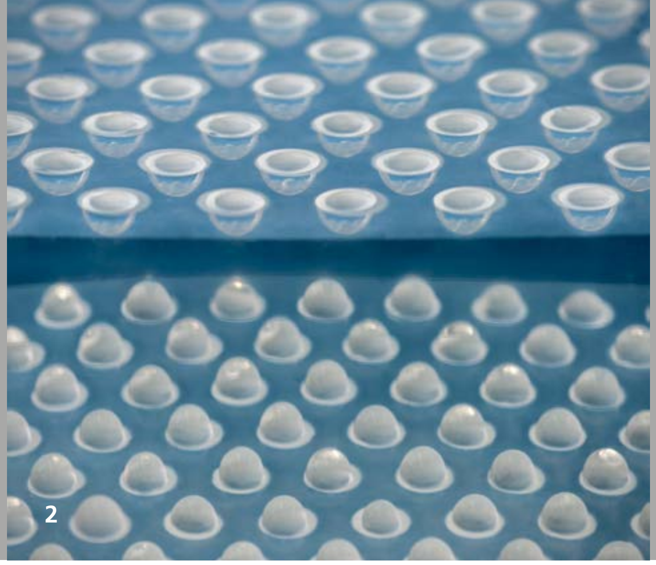
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LABBAG® – LABORATORY IN THE BAG

Human stem cells are considered as a new hope in personalized medicine. In the future, they should be used for example in the treatment of neuro-degenerative diseases. In a joint project coordinated by the Fraunhofer IST together with the Fraunhofer Institutes IBMT and IVV a closed surface-based cultivation system has been developed. By using the so-called LabBag® these cells can be cost-effectively, quickly, and aseptically cultivated, differentiated and cryopreserved.

Cultivation of stem cells
Scientists all around the world are trying to identify the potential of human stem cells to defend previously incurable diseases or are using these cells to perform fundamentally research on various diseases. For this the availability of high-quality, three-dimensional cellular material is indispensable, since these types of systems reflect much more effectively the conditions in the organism, than the previously used two-dimensional cell cultures. For cultivation of 3D aggregates the "hanging droplets" method is used. So far, cell aggregates of stem cells were generated either by pipetting robots, for which acquisition and maintenance are extremely expensive, or through manual pipetting. The latter is work- and time-intensive, requires a lot of practice, and involves a high risk of contamination.

In order to execute this process more cost-effectively and above all aseptically, the Fraunhofer Institute for Biomedical Engineering IBMT, the Fraunhofer Institute for Surface Engineering and Thin Films IST, and the Fraunhofer Institute for Process Engineering and Packaging IVV have come together and developed the LabBag®. In this mini-laboratory human induced pluripotent stem cells (hiPSC) can be cultivated in hanging droplets in a sterile environment to form 3D aggregates.

Coating for formation of hanging droplets
The coating on the inside of the bag developed at the Fraunhofer IST is crucial for the formation of the hanging droplets. This coating is applied by an atmospheric pressure plasma coating process and consists of a multiple layer system. By an initial coating, the internal surface becomes super hydrophobic and also repellent relative to the cell culture medium. In a second coating step hydrophilic spots are arranged on this surface, so that the cell culture medium is concentrated in these spots. In this manner several hundred hanging droplets are generated in the closed bag within a few seconds by simply shaking the bag. The cells sink into the droplets and within 72 hours form the desired 3D cell aggregates.

Advantages of the LabBag®
The coating procedure by an atmospheric pressure plasma process is a dry process, so that no solvents are used in the process. This is a great advantage, as residues of the solvent might influence cell viability. The desired layer properties can be adjusted by the used process gases and the film-forming agents so that an optimized surface for the formation of the hanging droplets occurs.

Further advantages of the LabBag® are:

- Lower personnel and material costs
- Increased cell yield and process reliability
- Easy adjustment of the droplet volume and thus the aggregate sizes by variation of the deposited spot diameters on the bag surface
- Cryo-conservation of the cells within the LabBag®

Outlook
Further developments and future applications for the LabBag® are:

- Integration of sensors for cell monitoring
- Generation of additional layer functions within the bag
- Further development of the LabBag®, e.g. for the use in veterinary medicine
- Optimization of the LabBag® for medication screening in the development of pharmaceutical products

1 LabBag® – a closed mini-laboratory for 3D cell cultivation.

2 Hanging droplets for the formation of 3D cell models.

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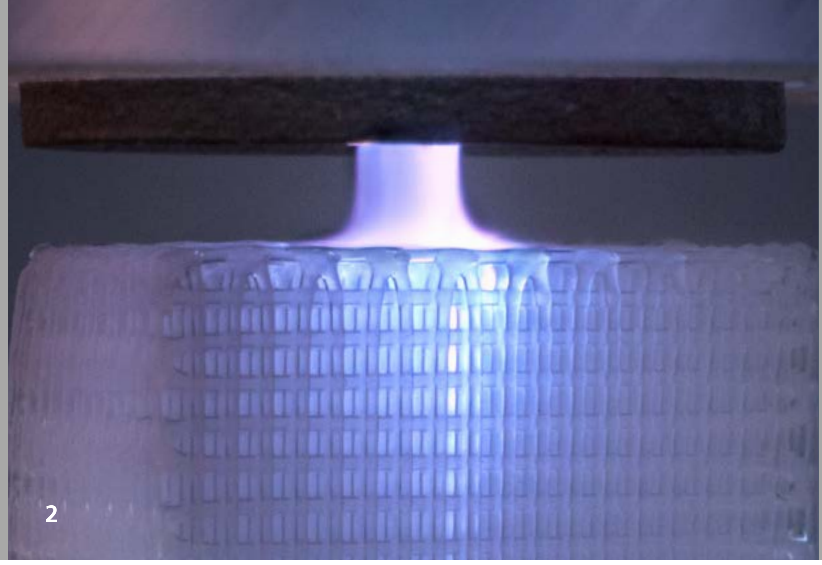


2

PLASMA JET FOR COATINGS WITH FUNCTIONAL GROUPS

A new approach for the medical treatment of missing bone fragments is the implanting of 3D printed and biodegradable polymer frameworks, so-called scaffolds. These have the task of serving as a framework for new growing bone cells, and then over time to decompose within the body. For optimal growth of the new bone cells the surface of the polymer must be chemically treated by nucleophilic and electrophilic groups. One possibility that is being investigated at the Fraunhofer IST is the deposition of layers with suitable chemical groups via atmospheric pressure PECVD by a plasma jet during the 3D printing process.

Development of the technology

At the Fraunhofer IST a plasma jet mounted on a robot (see Fig. 1) is used for deposition of PECVD layers. A layer forming precursor is added to the argon plasma that is used, which results in a local layer deposition in front of the plasma nozzle. The directed gas flow should enable penetration of the film into the porous scaffold structure (see Fig. 2).

Through variation of different process parameters, such as precursor gas, gas flows, electrical power, oxygen supply, pulse pattern or substrate temperature, the influence of the individual parameters was more precisely investigated for the layer properties. The plasma jet used causes only a very low energy input of maximum 4 W on the substrate to be coated, so that substrate temperatures of 60 °C are not exceeded during the coating process. Thus, the test arrangement is also excellently suited for the coating of temperature-sensitive, porous polymer structures.

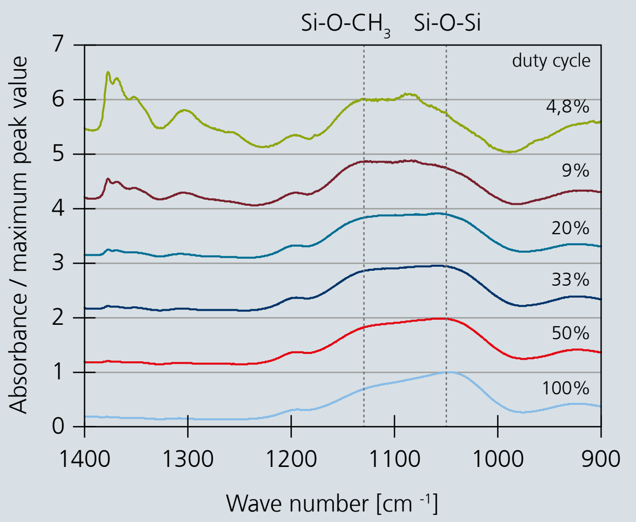
Results

With the approach described above it was possible to deposit layers with different precursors, such as HMDSO, TMS, APTMS, GMA, and MAA-VTMOS. In this regard, for nucleophilic pp-APTMS layers, in particular it became clear that the pulse pattern has a major influence on the density of the nucleophilic groups. If the layers are deposited with a minimal duty cycle, i. e. with a low ratio of pulse to period duration, then the molecular structure of the precursor remains better preserved and layers with higher group densities are generated (see the opposite graphs). A moderate increase in the substrate temperature to 70 °C during a deposition process also had a positive effect on the nucleophilic group densities of the pp-APTMS layers. Moreover, it was also possible to successfully transfer the layer deposition of planar substrates to 3D scaffold substrates.

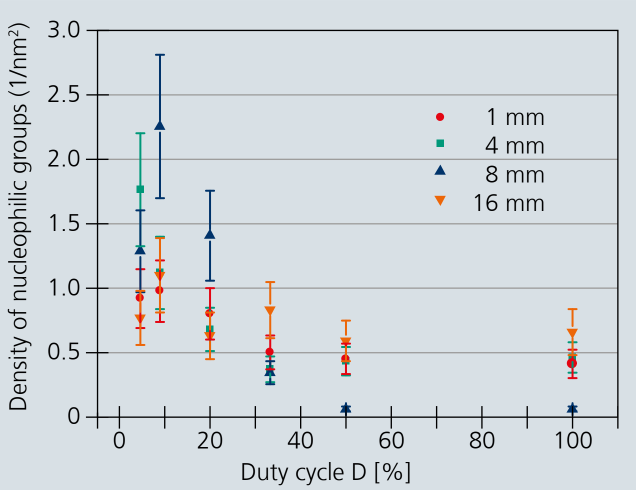
Outlook

Current and future investigations of this topic are increasingly focused on layer stability relative to storage and sterilization processes. In addition, it is planned to conduct studies concerning cell growth on coated substrates.

ATR-FTIR spectra of pp-APTMS layers for different duty cycles.



Density of nucleophilic groups as a function of the duty cycles.



1 *Robot arm with plasma jet in operation.*

2 *Layer deposition by plasma jet.*

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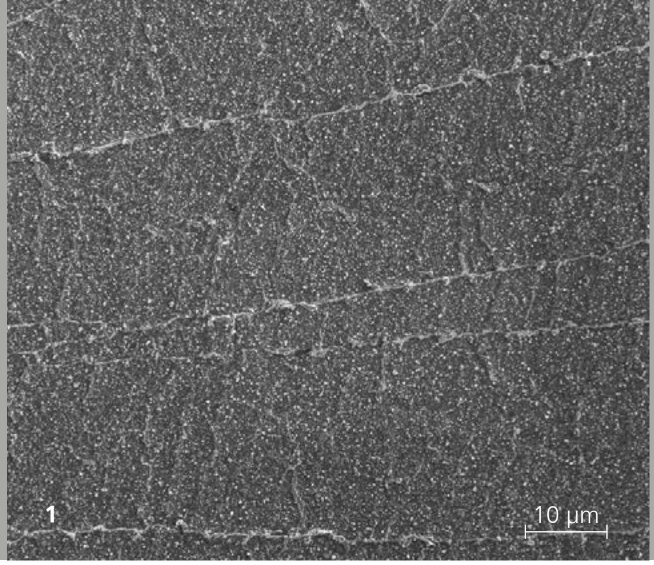

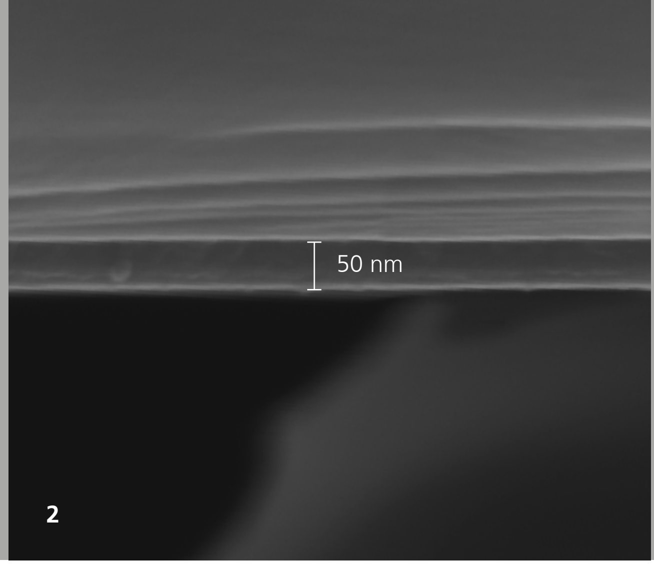

ATOMIC LAYER DEPOSITION IN FLUID SYSTEMS

Uniform inner coatings in fluidic systems with nanometer-thick layers poses a special challenge. Often the diffusion limits uniform deposition of layers extending into the rearmost corners of the extremely long and narrow channels. The objective of the work at the Fraunhofer IST is to homogeneously precipitate compact layers in complex fluidic systems even at low temperatures by atomic layer deposition at atmospheric pressure.

Atomic layer deposition (ALD)

Atomic layer deposition is a chemical gas phase process. The characteristics of the process are two self-limiting successive surface reactions, so that extremely thin and low-defect layers can be deposited. Usually, two gases are used, which are separately routed over the surface through an alternating inert gas flushing.

For the investigations at the Fraunhofer IST trimethyl aluminum (TMA) was used as the layer former, which is deposited as an atomic layer when gases flow over the surfaces. Excess TMA is removed in a subsequent flushing step. Via inert gas that contains water vapor the TMA layer can then be oxidized, so that aluminum oxide Al_2O_3 is formed. The excess water vapor is removed in a subsequent flushing step. Optionally the process then starts over again and an additional monolayer TMA can be deposited on the surface. In this manner compact, homogeneous layers are deposited through cyclic film and subsequent oxidizing with water vapor. For standard processes the gas exchange is supported through evacuation of the process chamber and temperatures of more than 100 °C.

ALD at atmospheric pressure

With conventional ALD processes at vacuum, the diffusion limits layer deposition through the channel openings and fluidic systems. Moreover, for the coating of plastic sufficiently low process temperatures of less than 100 °C are required. Consequently, at the Fraunhofer IST ALD processes have been developed that are suitable for fluidic systems with long channels of plastic.

For the investigations of the Fraunhofer IST the reactive gases cited above flow directly through PVC tubes with a 4 mm diameter and are flushed with inert gas. The high flow speed in the channels permits a fast exchange between the reactive gas mixtures so that the cycle time could be reduced to 120 s. Even at a process temperature of 50 °C closed layers could be deposited in the tubes (see Fig. 1). Tests with a small reactor showed that at the same parameters compact layers can even be deposited on silicon (see Fig. 2).

Outlook

The homogeneous, nanometer-thick inner film of fluidic plastic systems is also interesting for the deposition of diffusion barriers, because the surface contour remains intact at minimal layer thicknesses. Moreover, through the virtually unlimited lengths of the channel systems to be coated additional varied application possibilities arise, such as the inner coating of heat exchangers or cooling systems.

1 Compact Al_2O_3 coating in a PVC tube after 250 cycles.

2 Fracture edge of a 50 nm thick Al_2O_3 coating on silicon, produced after 500 cycles.

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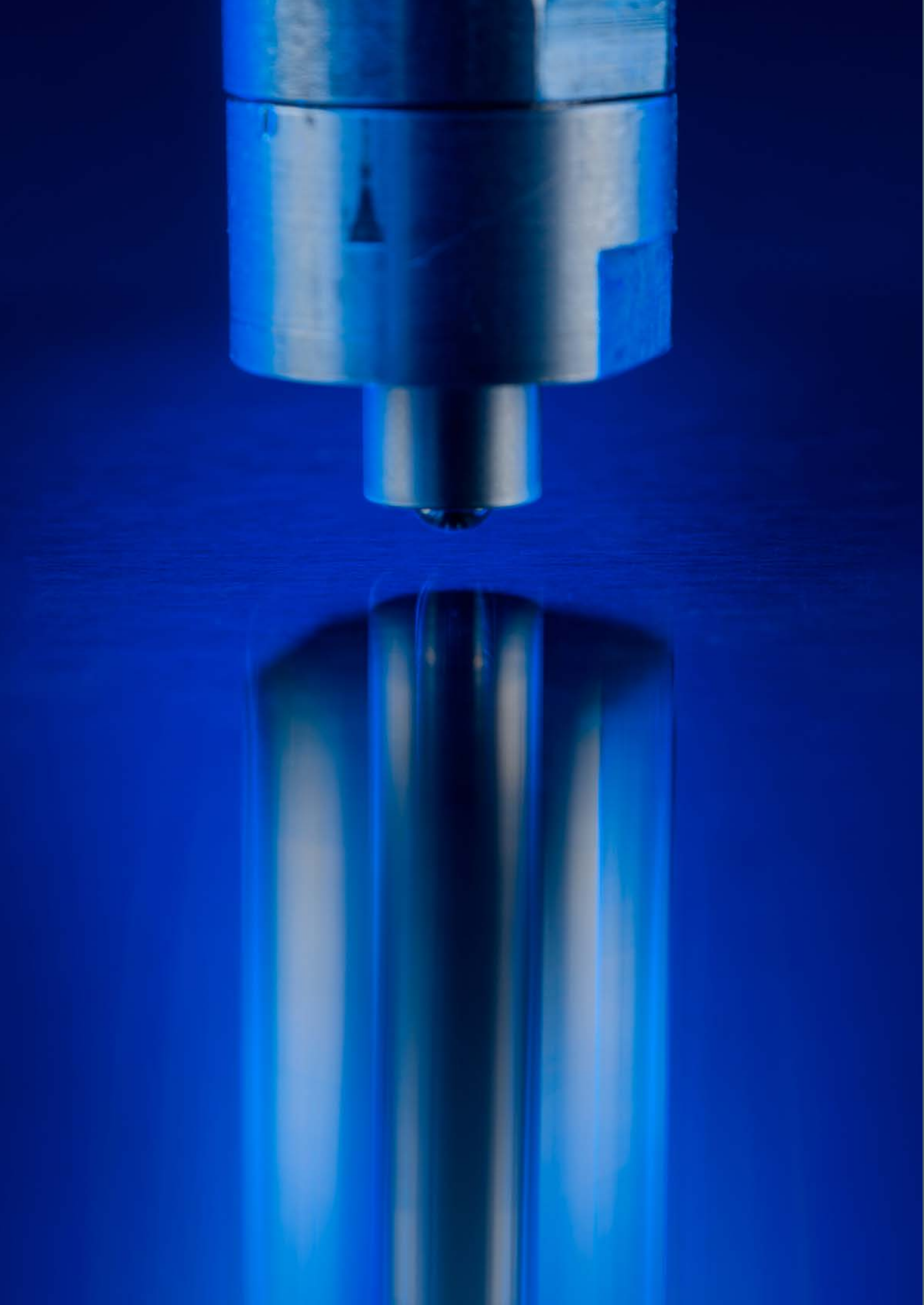
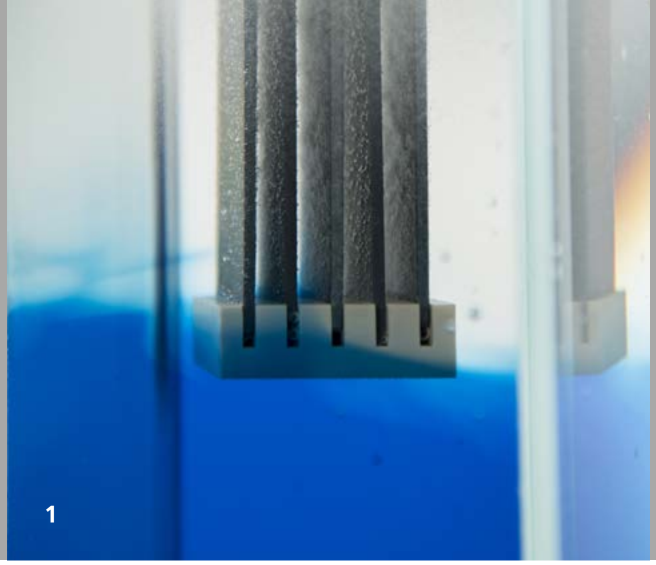


SERVICES AND COMPETENCIES

In pursuing the business units that were showcased in the previous chapters the Fraunhofer IST utilizes a wide spectrum of competencies. The focus is on these technologies:

- Physical vapor deposition
- Chemical vapor deposition
- Plasma diffusion
- Atmospheric pressure plasma processes
- Electrochemical processes
- Laser technology

In addition the Fraunhofer IST provides recognized competencies for a variety of coating systems. The institute offers a broad spectrum of cross-sectional services: Surface pretreatment, thin film development, surface modification, process technology (including process diagnostics, modeling and control), surface analysis and thin film characterization, training, application-oriented film design and modeling, simulation, system design, device and equipment manufacturing and technoloy transfer.



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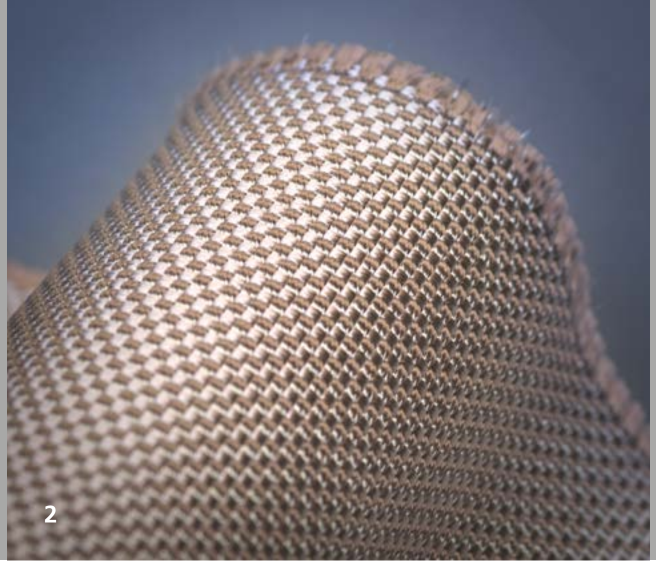

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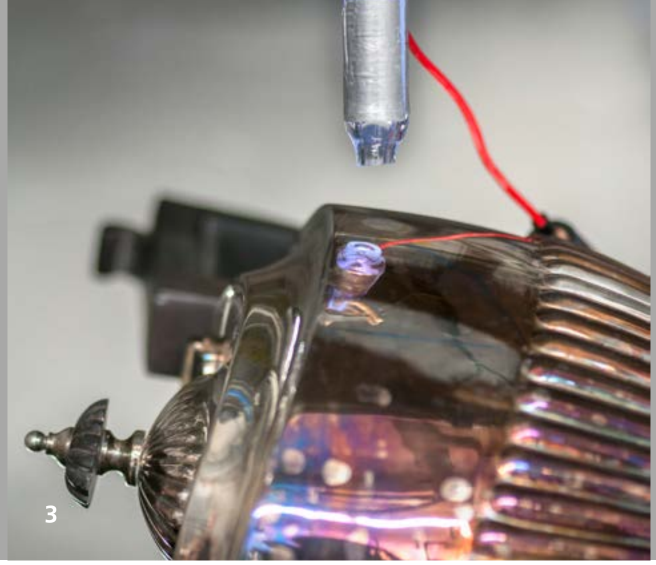

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COMPETENCE LOW PRESSURE PROCESSES

Physical Vapor Deposition (PVD)

- Magnetron sputtering
- Highly ionized pulsed plasma processes like HIPIMS, MPP
- Hollow cathode processes

Chemical Vapor Deposition (CVD)

- Hot-wire-CVD
- Atomic layer deposition (ALD)
- Plasma-enhanced CVD (PECVD)

Plasma diffusion

- Nitriding / Carbonitriding
- Oxidizing
- Boriding

COMPETENCE ATMOSPHERIC PRESSURE PROCESSES

Atmospheric pressure plasma

- Micro plasma
- Plasma printing
- Dielectric barrier discharge / Corona treatment
- Low temperature bonding
- Plasma medicine
- Plasma particle coating and cold plasma spraying

Electrochemistry

- Multi component systems for electroplating
- Non-aqueous electroplating
- Electrochemical processes

Laser technology

- Laser plasma hybrid processes
- Laser induced fluorescence
- Laser structuring

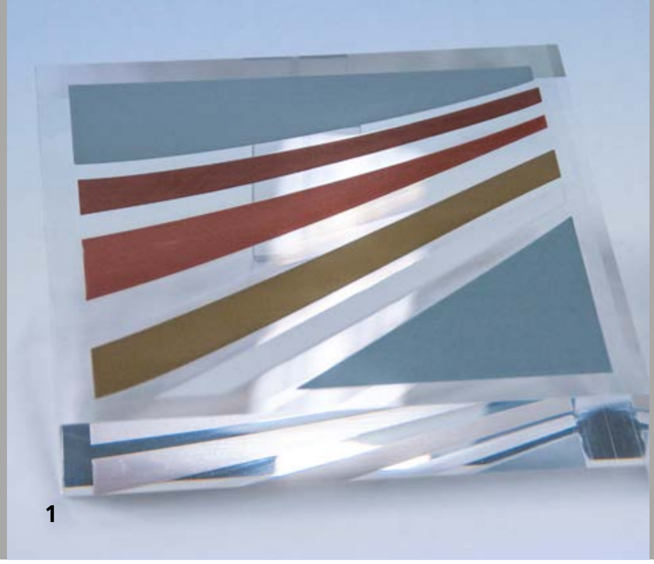
Layer by layer processes

- Polyelectrolyte coatings
- Biofunctional coatings
- Chemical derivatization

1 *Water purification by means of diamond electrodes.*

2 *Depths functionalization of metal-textile-composite materials.*

3 *Plasma jet treatment for removing tarnished films on silver objects.*



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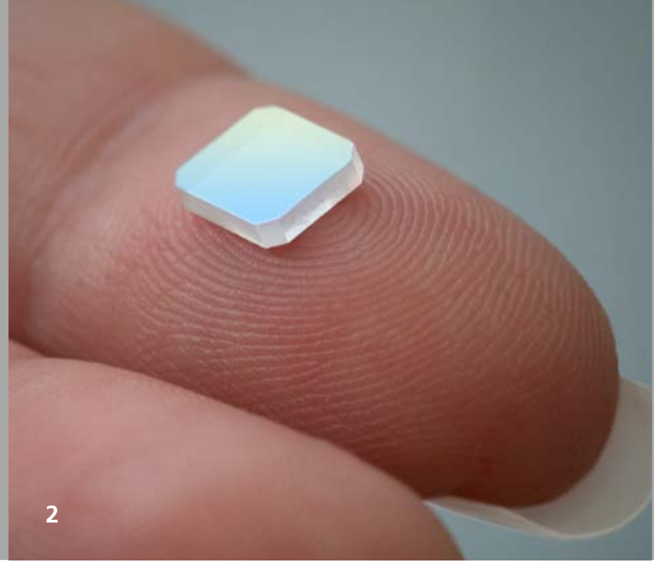

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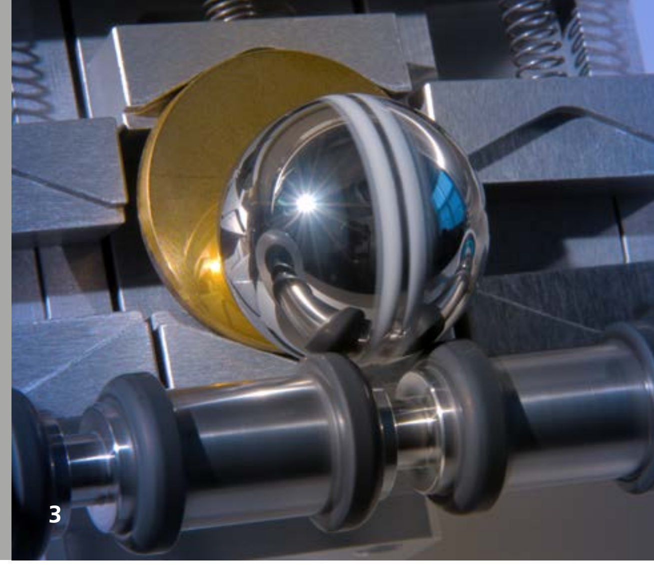

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COMPETENCE COATINGS SYSTEMS

Friction reduction and wear protection

- Amorphous carbon coatings (DLC)
- Diamond coatings
- Hard coatings
- Nitride / Cubic boron nitride (cBN)
- Metal coatings
- Plasma diffusion / DUPLEX processes
- Dry lubricants
- Erosion protection
- Corrosion protection
- Anti-adhesion and antifouling coatings
- Diffusion barriers

Electrical and optical coatings

- Precision optics
- Transparent conductive coatings
- Electrochromic coatings
- Low-E and sun control coatings
- Diamond electrodes
- Silicon-based coatings for photovoltaics and micro electronics
- Semiconductors (oxide, silicon-based, diamond)
- Insulation coatings
- Piezoelectric coatings
- Plastics metallization

Micro and nano technology

- Thin film sensor technology
- Micro technology
- Nano composites
- Control of coating adhesion
- Structured surface coating and activation

Biofunctionalization

- Antibacterial coatings
- Adhesion and anti adhesion coatings
- Chemical reactive surfaces

Photocatalysis

- Air and water purification systems
- Photocatalytically active coatings with antimicrobial effectiveness

FURTHER COMPETENCIES

Pretreatment and functionalization

- Wetchemical cleaning
- Functionalizing and coating of interfacial layers
- Surface structuring
- Plasma activation
- Oxidation and reduction of metals
- Plasma surface modification of natural products

Simulation

- Simulation of plants, processes and coating layer properties
- Model based interpretation of coating processes

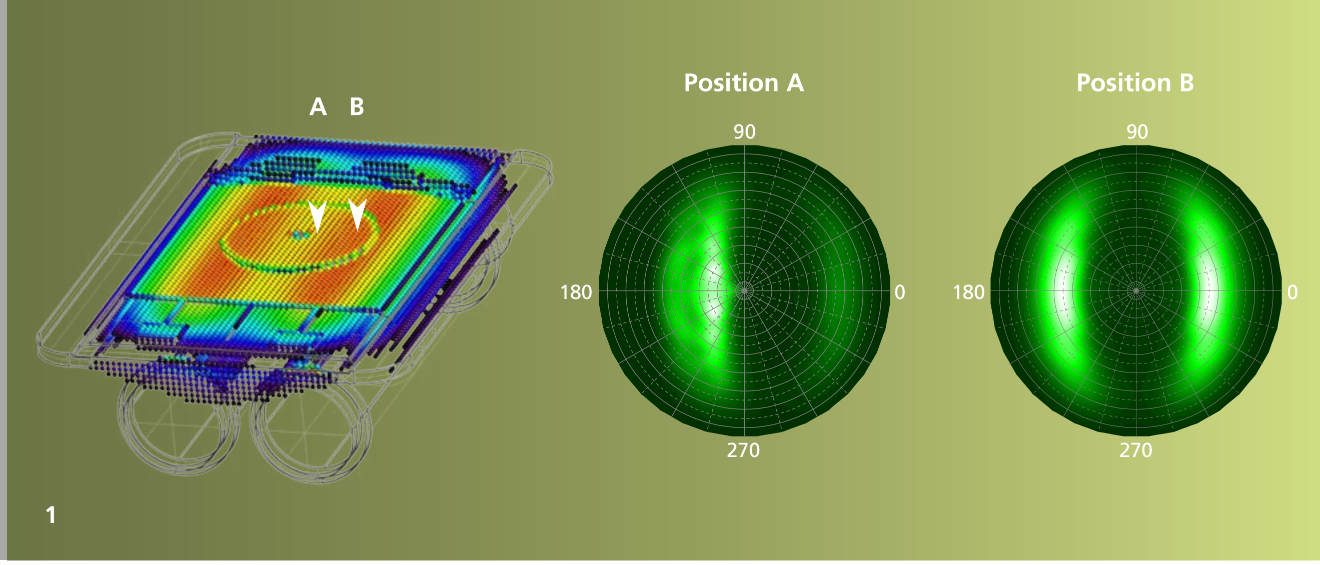
Analytics and quality assurance

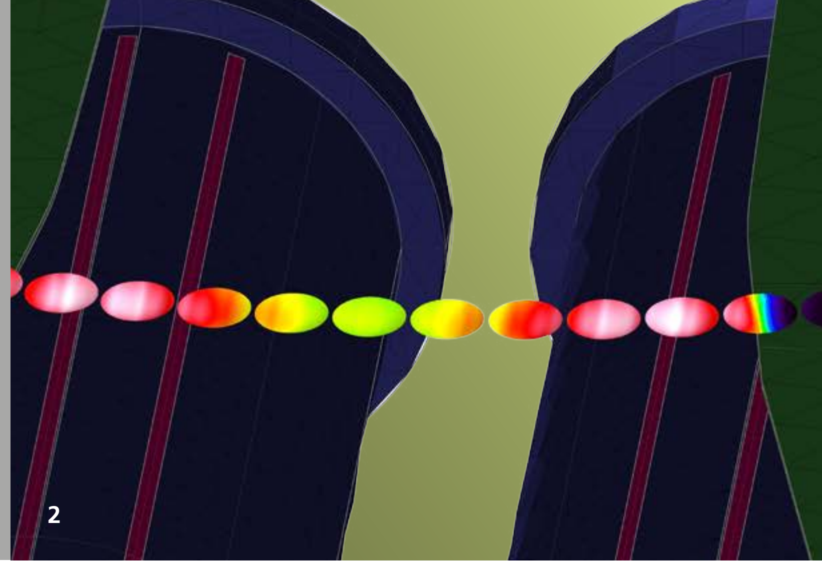
- Chemical analysis
- Crystal structure analysis
- Microscopy
- Analysis of chemical reactive surfaces
- Optical and electrical characterization
- Plasma diagnostics
- Tribological tests
- Mechanical tests
- Standardized photocatalytically measurement technology including test systems and devices

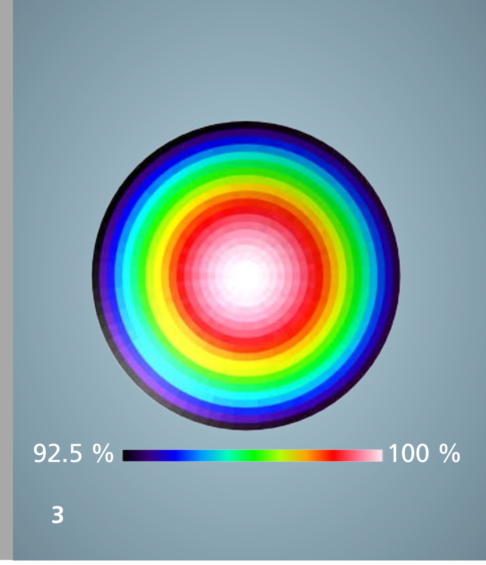
1 *Coatings of aluminium, copper oxide, copper, brass, PE and stainless steel, deposited by plasma particle technology.*

2 *Infrared bandpass filter with broad blocking for an application directly on the CCD Chip in a Mars mission.*

3 *Rotating ball of the calotte grinding method.*







MODELING OF THE COATING ON 3D COMPONENTS

Coatings on 3-D substrates are gaining increasing significance in various application areas. Examples are optical film systems on lenses, coatings onto curved vehicle windows or curved display surfaces. Via kinetic simulation methods, coating processes can be modeled in the low-pressure range and thus the film thickness profile can also be predicted. Unlike flat surfaces, for 3D substrates the substrate angle relative to the coating source also plays an important role. Therefore, for coating processes onto moving 3D substrates the movement sequence would need to be subdivided into small steps and a coating simulation would be required for each sub-step. Because this is extremely time intensive, a new method for accelerated modelling of the film thickness profile on 3D substrates has been developed at Fraunhofer IST.

The simulation method

The "Direct Simulation Monte Carlo" (DSMC) method is suitable for modeling of flow and transport phenomena in low-pressure coating processes. This method describes the movement of molecules and atoms via representative simulation particles and presents a statistical approach for solving the Boltzmann transport equation. For example, DSMC is suitable for modeling the gas flow and film thickness profile in magnetron sputtering. In the case of moving 3D substrates, subdividing the motion sequence into many sub-steps, each of which requiring execution of the DSMC calculation, would be too time-intensive.

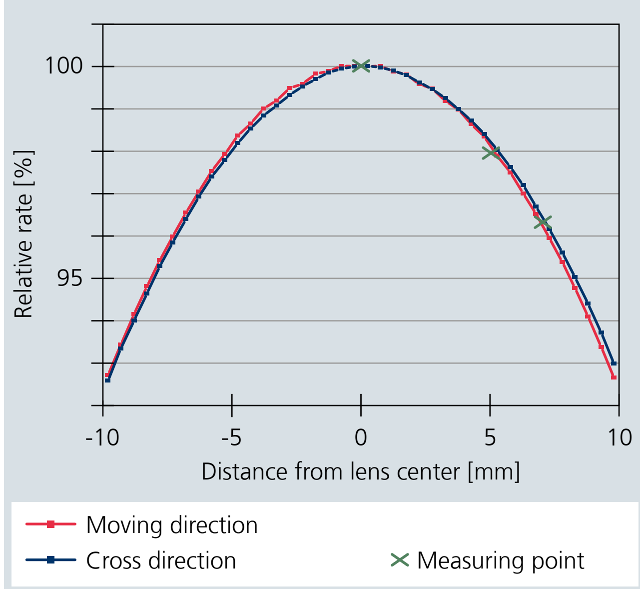
On the other hand, the newly developed simulation method requires only a single DSMC simulation. In this simulation, in a plane near the substrate the particle flow profile is sampled in lateral as well as in angular resolution and stored as intermediate dataset. Via a ray-tracing algorithm projecting the angular resolved flux density onto the substrate, this dataset allows for fast computation of the film thickness profile for 3D substrates in arbitrary positions. This is a viable approach because the scattering of sputtered particles in the gas can be ignored for the remaining minimal distance between sampling plane and substrate. Thus, this procedure enables a fast calculation of the film thickness profile for moving 3D substrates with fine resolution of the movement sequence. One example of location-resolved and angle-resolved particle flow distribution in a model of a sputter chamber is presented in Fig. 1.

Example: Dynamic coating of a lens

Starting with the particle flow profile shown in Fig. 1 and the selected aperture shape, the coating onto a spherical lens that is moved through the coating zone on a turntable can be quickly calculated via the ray-tracing method. The lens has a diameter of 20 mm and on the convex side a radius of curvature of 25.8 mm. Fig. 2 shows the partial film profiles on the lens surface for different positions of the movement sequence, as well as the overall profile resulting from the sequence. The discretization of the rotary plate movement occurs in the overall profile with an angular accuracy of 0.1°, the overall computation time is only a few seconds on a single CPU, and the resulting rate profile on the lens is consistent in good approximation with the measured data (see adjacent diagram).

The new, combined calculation method enables efficient calculation and optimization of film thickness distribution, and in principle this can be extended to any curved substrate shape.

Calculated film profile on the lens surface in the movement direction of the turntable (red), and in the transverse direction (blue) compared to film thickness measurements.



1 Simulated particle flow profile of sputtered atoms near the substrate plane and angular distribution functions at selected points.

2-3 Partial film profiles of a lens at different positions and the accumulated overall profile.

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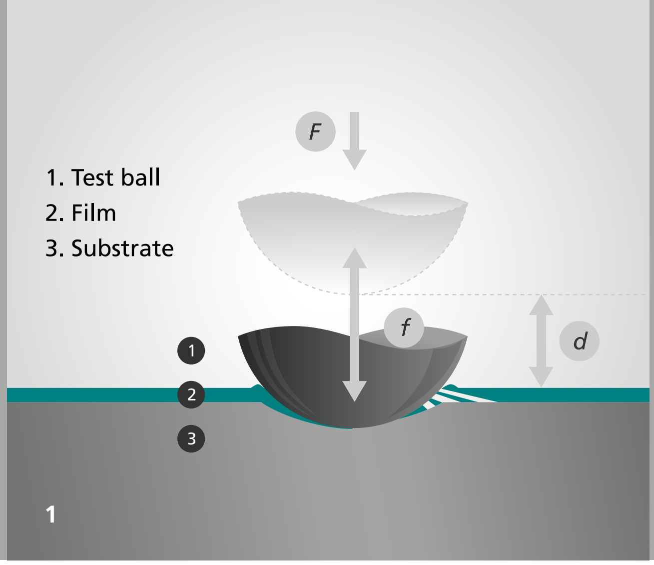

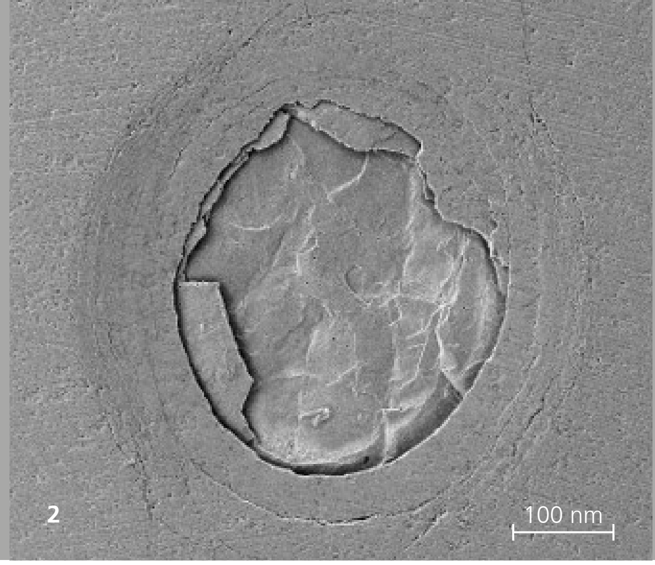

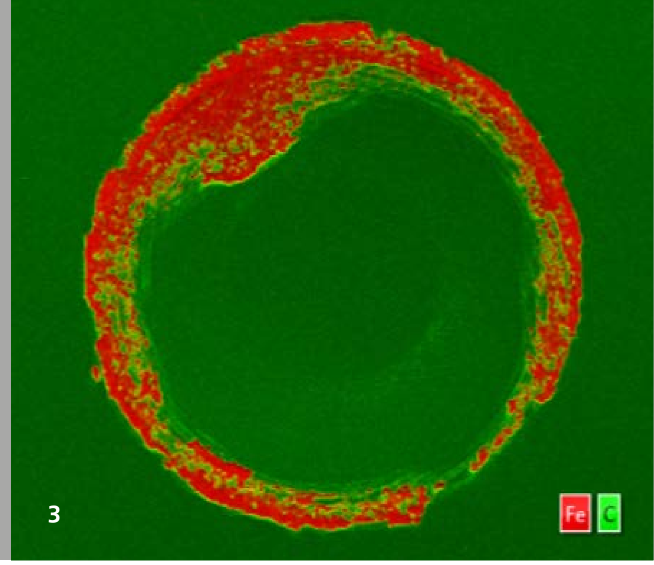

TESTING THE SERVICE LIFE OF HARD MATERIAL FILMS

In addition to pure static forces, thin PVD and CVD hard material films are also subjected to dynamic forces in many applications. Not infrequently after exceeding a critical alternating stress level they experience a fatigue fracture or other signs of fatigue, such as pitting or near-surface micro-crack formations. In order to approximately predict this situation the susceptibility of a film system can be tested with the aid of the impact test available at Fraunhofer IST. In this regard the resistance of a film-substrate composite is examined for material damage, crack formation, and delamination.

The test principle
The impact test is a dynamic alternating stressing of the film-substrate composite that can be performed on flat components as well as curved components. For this test a fixed, clamped-in test ball exerts a cyclic load on the component to be tested with a frequency [f] of approximately 60 Hz. Depending on the selected operating mode two different dynamic loads can be set. For the first variant, so-called non lift-off operation, the load occurs in continuous contact of ball and component. In this case the distance [d] equals zero (see Fig. 1). The second mode, lift-off operation, is a hammering movement of the ball on the component. In this mode the distance [d] is at least 0.2 mm. Via an electromagnetic drive, test forces [F] between 200 N and 4000 N can be adjusted.

The test balls
The material and the size of the test balls that are used have an influence on the stresses to the film system. A changed surface pressure occurs depending on the size of the ball. Ceramic test balls are better suited for long test periods > 10^5 impacts and concurrent high loads of ≥ 2000 N, than are steel balls (100Cr6), for example. At these loads, the latter tend to show signs of material fatigue, which usually go hand-in-hand with an irregular material removal on the ball and thus an uneven pressure distribution. Moreover, such a material transfer can make a subsequent EDX analysis more difficult

First results
The size of the impact impressions, i. e. the diameter and the depth, as well as the so-called pile-up behavior, a bulging in the edge area of the impressions, increases with increasing test force. For example, at a test force of 500 N, a diameter of approximately 450 µm and a depth of approximately 7 µm are determined. On the other hand, at a test force of 4000 N the diameter is approximately 900 µm, and the depth is approximately 50 µm.

Multiple tests, as a rule two or three, are required for an evaluation of layer adhesion. In this regard the interval between the individual tests must be selected in such a manner that the tests do not reciprocally influence each other.

Investigation of service life
Due to the recurring load and offload cycles the layer system is subjected to strong stress, which can result in layer flaking and/or expansion cracks in the area of the impact impression. Using optical images or with the aid of REM-EDX photographs the degree of layer system damage can be determined. Figures 2 and 3 show photographs with considerable layer damage. The scope of the defects serves as an indicator for the service life of the film. For very rough surfaces premature layer damage can occur, since high surface pressures occur on the roughness asperities. Moreover, with the aid of a transverse section it is possible to determine the extent to which the substrate underneath the film has been damaged.

1 *Schematic diagram of the impact test.*

2 *Damaged film after the impact test.*

3 *Example of an EDX analysis (green = intact film; red = flaked film).*

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NAMES, DATES, EVENTS 2017

In 2017 the Fraunhofer IST once again appeared on various platforms. An overview of the most important events and activities of 2017 follows:

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TRADE FAIRS, EXHIBITIONS, CONFERENCES

18th Syposium for Plasma Technology PT-18
Göttingen, February 20–22, 2017. For the first time the Application Center for Plasma and Photonics of the Fraunhofer IST took part at the accompanying exhibition of the Syposium for Plasma Technology in Göttingen and presented the latest research developments in the field of plasma particle technology. Furthermore, the Fraunhofer IST participated in the program with numerous lectures.

Hannover Messe 2017
Hannover, April 24–28, 2017. This year the Fraunhofer IST was again represented in two halls of the Hannover Messe. At the "surface" area of the joint Fraunhofer booth in hall 2 the Application Center for Plasma and Photonics of the Fraunhofer IST presented its innovative technology cold plasma spraying as well as a new developed plasma source which can treat even three-dimensional substrates true to the contour. The institute's current research results in the field of micro and sensor technology were presented at the "adaptronics" area. In addition, the Fraunhofer IST was also represented at this year´s joint booth "Plasma and laser surface technology" in hall 6. There, the Fraunhofer IST showed the latest developments in the field of mechanical engineering, tools and automotive technology.

SVC TechCon 2017
Providence, Rhode Island, USA, April 29–May 4, 2017. As in previous years representatives of the Fraunhofer IST participated in the SVC TechCon's program with numerous contributions. In addition the institute showed among others its latest results in the field of HIPIMS technology during the accompanying exhibition.

TechTextil 2017
Frankfurt, May 9–12, 2017. For the first time the Fraunhofer Technical Textiles Alliance, founded in 2016, made its appearance at this year's trade fair TechTextil in Frankfurt. The 14 member institutes presented the bundled Fraunhofer expertise in the textile value chain. The Fraunhofer IST presented textile surfaces with different functionalizations, such as awning fabrics, which were impregnated very effectively wet chemically by a previous plasma coating.

Biotechnica 2017
Hannover, May 16–18, 2017. The Fraunhofer IST presented its current research results in the field of life sciences such as plasma coated cell culture bags at a joint Fraunhofer booth at the trade fair Biotechnica.

8th International Conference on High Power Impulse Magnetron Sputtering (HIPIMS)
Braunschweig, June 13–14, 2017. In cooperation with the Sheffield Hallam University and the Network of Competence INPLAS e. V., the Fraunhofer IST organized again the international conference on HIPIMS (High Power Impulse Magnetron Sputtering). Also this year, representatives of the Fraunhofer IST participated with numerous contributions to the scientific conference program.

Paris Air Show 2017
Le Bourget, France, June 23–25, 2017. As part of the Fraunhofer Space Alliance the Fraunhofer IST was also represented at the Paris Air Show 2017 in this year with the focus on "optical applications in space".

LASER World of Photonics 2017
München, June 26–29, 2017. At the LASER World of Photonics 2017 the Fraunhofer IST showed its latest developments in the field of laser plasma hybrid technology at the joint Fraunhofer booth. This new process combines laser technology and atmospheric pressure plasma processes and enables more efficient, higher-quality and therefore more economical production as well as processing procedures. Furthermore, the institute presented various optical filters which were produced by the innovative sputtering system EOSS®.

Parts2Clean 2017
Stuttgart, October 24–26, 2017. Also in this year the Fraunhofer Cleaning Technology Alliance organized a joint booth at the Parts2Clean. The Fraunhofer IST showed the latest research results in the field of surface cleaning by using plasma and exhibited among others the innovative plasma source concept "Disc-Jet": The jet can treat even temperature-sensitive substrates contoured and depth processing.

Space Tech Europe
Bremen, October 24–26, 2017. For the first time the Fraunhofer IST participated at the Space Tech Europe as a member of the Fraunhofer Space Alliance. In addition to further components for aerospace the Fraunhofer IST presented a metallized mirror made of carbon fiber reinforced plastic (CFRP) which can resist extreme temperature fluctuations in space.

1-3 *Appearance of the Fraunhofer IST at the Hannover Messe 2017. (1) View of the joint booth "Plasma and laser surface technology" in hall 6, (2) Disc-Jet of the Application Center for Plasma and Photonics of the Fraunhofer IST, (3) the area "adaptonics" at the joint Fraunhofer booth in hall 2.*

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EVENTS, COLLOQUIA, WORKSHOPS

1st Science day at the Fraunhofer IST
Braunschweig, January 24, 2017. For the first time the "science day" took place at the Fraunhofer IST this year. PhD students of the Fraunhofer IST and the Institute of Surface Technology of the TU Braunschweig presented posters with the latest results of their doctoral studies. All employees were invited to inform themselves on this occasion about current research topics and to discuss in an informal setting.

Cloud of science
Braunschweig, September 15–27, 2017. In 2007 Braunschweig was chosen as the "city of science". To celebrate the 10th anniversary year, the city of Braunschweig and the ForschungRegion Braunschweig e. V. set up a network in the form of a "cloud of science" at the Burgplatz. Under the cloud a varied and rich public event program took place which was designed by numerous regional research institutes. The Fraunhofer IST also participated with two contributions: "silver cleaning by means of plasma" and "plasma in everyday life".

On September 20, 2017, the scientists presented an innovative cleaning method for tarnished silver surfaces: the treatment with "cold plasma". Silver jewelry, cutlery or other surfaces which are exposed to the ambient air, tarnish after a while, resulting in the well-known brown-black discoloration. Especially during restoration work these dark layers should often be removed. With the new pen-like jet systems developed at the Fraunhofer Institute for Surface Engineering and Thin Films IST, even temperature-sensitive materials such as brocade fabrics can be processed with silver threads.

Two days later, colleagues from the Application Center for Plasma and Photonics of the Fraunhofer IST showed how plasma technologies can be used in easy-to-use handsets in everyday life. Examples are the PlasmaDerm® device for the treatment of chronic wounds such as open legs and skin diseases like atopic dermatitis or the "plasma lice comb", which releases the head of lice and nits without the use of aggressive shampoos and which will be available in the near future. In all devices, the ambient air is ionized by means of electricity and transferred to the plasma state. Different plasma-chemical and physical effects then change the properties of the treated surfaces.

The jubilee event concluded with a panel discussion on the topic "future questions of human kind". More than 20 representatives of research institutes from Braunschweig, among them the director of the Fraunhofer IST, Prof. Bräuer, discussed how the forecast of the future has changed over the past decade.

Workshop "Additive manufacturing meets surface technology"
Braunschweig, November 29–30 November, 2017. "Additive Manufacturing" is one of the most important keywords in the age of Industry 4.0, and the further developments in the field of additive manufacturing play a major role in surface technology as well. As part of the event series "INPLAS Talks" of the Network of Competence INPLAS e. V., the interaction between these two technologies was explained in numerous lectures and workshops. The Fraunhofer IST participated with a lecture at the program.

PRIZES AND AWARDS

1st Poster prize at the SVC 2017
Jessica Gerstenberg from the Institute of Surface Technology of the TU Braunschweig was honored with the first place in the poster prizes for her poster "Microstructure Investigations on Gas Flow Sputtered Thermal Barrier Coatings" together with her coauthors from the Fraunhofer IST and the Institute of Materials of the TU Braunschweig. In her research study she examined zirconium-based thermal barrier coatings produced by means of gas flow sputtering e. g. with regard to the resulting microstructure of the layer.

Competition INNOspace Masters 2017
Once again Dr. Andreas Dietz, manager of the business unit aerospace, took the 2nd place in the INNOSpace Masters competition in the category "DLR Raumfahrtmanagment Challenge". The aim of the awarded project AMPFORS (Additive Manufacturing of Polymer Parts for Space) is to develop more and more lightweight 3D printed plastic components for aerospace. In a second step the printed parts are metallized, for example to improve the mechanical properties of plastic and to adapt it to the conditions in space.

K-T Rie-Award 2017
Prof. Dr. Günter Bräuer was honored with the K-T Rie Award at this year´s Asian-European International Conference on Plasma Surface Engineering (AEPSE) for his work in the field of applied plasma science. The award honors the scientific lifetime work of the PhD physicist: his contribution to the promotion of applied plasma science and technology, not only in Asia but worldwide. "This award means a lot to me," says Bräuer. "It shows me that my activities are perceived and appreciated."

1-2 *The two appearances of the Fraunhofer IST during the "cloud of science" event at the Burgplatz in Braunschweig: (1) "silver cleaning by plasma" and (2) "plasma in everyday life".*

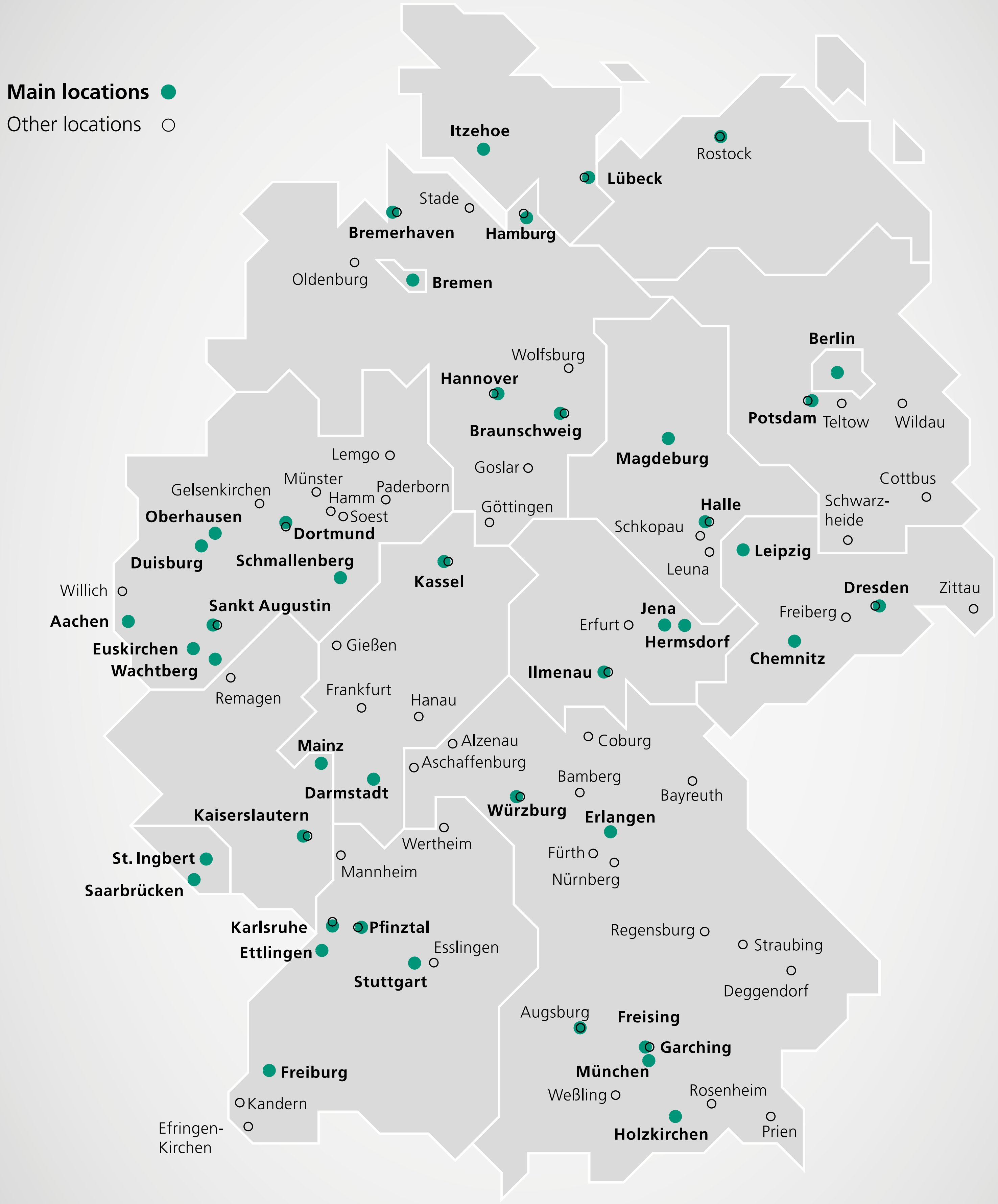
3 *The winner of the 1st poster prize of SVC 2017 Jessica Gerstenberg (center).*

4 *Prof. Dr. Günter Bräuer (right) receives the K-T Rie award for his achievements in the field of applied plasma research.*

THE FRAUNHOFER IST IN NETWORKS

With its research and development activities the Fraunhofer Institute for Surface Engineering and Thin Films IST forms a part of various internal and external networks which function with different points of emphasis in the field where business, science and politics interact and even clash. Within the Fraunhofer-Gesellschaft the institute pools its competences with those of other Fraunhofer institutes in, amongst other things, the Fraunhofer Group for Light & Surfaces and in various Fraunhofer alliances in order to be able to offer customers and partners optimal – and even cross-technology – solutions for their specific tasks.

In addition the Fraunhofer IST also keeps an eye open for future scientists and researchers. For this reason the institute networks intensively with educators, students and pupils in order to arouse an enthusiasm for the natural sciences and engineering at an early age and to encourage the upcoming generation of scientist.



THE FRAUNHOFER-GESELLSCHAFT AT A GLANCE

Research of practical utility lies at the heart of all activities pursued by the Fraunhofer-Gesellschaft. Founded in 1949, the research organization undertakes applied research that drives economic development and serves the wider benefit of society. Its services are solicited by customers and contractual partners in industry, the service sector and public administration.

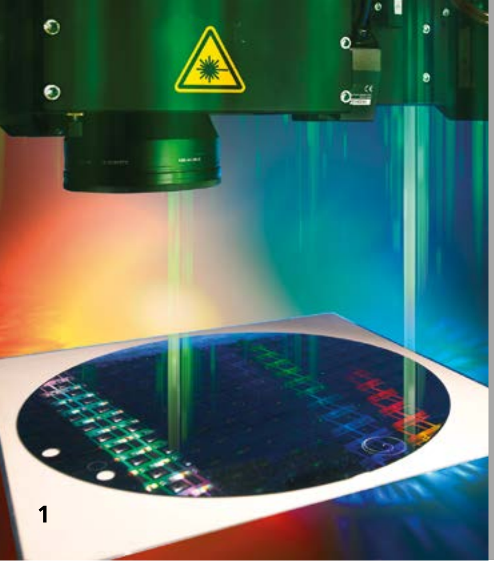
At present, the Fraunhofer-Gesellschaft maintains 72 institutes and research units. The majority of the more than 25 000 staff are qualified scientists and engineers, who work with an annual research budget of 2.3 billion euros. Of this sum, almost 2 billion euros is generated through contract research. Around 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Around 30 percent is contributed by the German federal and state governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

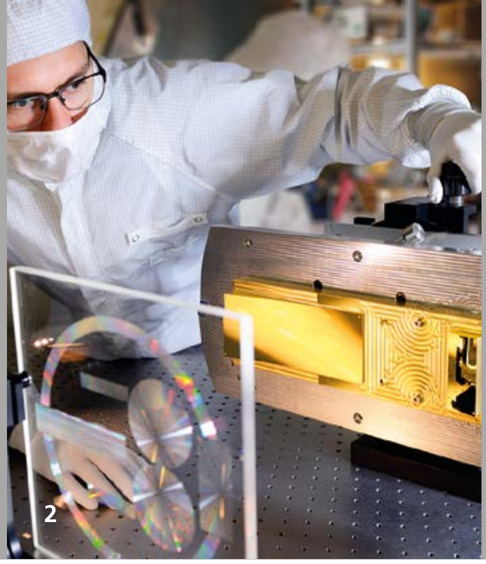
International collaborations with excellent research partners and innovative companies around the world ensure direct access to regions of the greatest importance to present and future scientific progress and economic development.

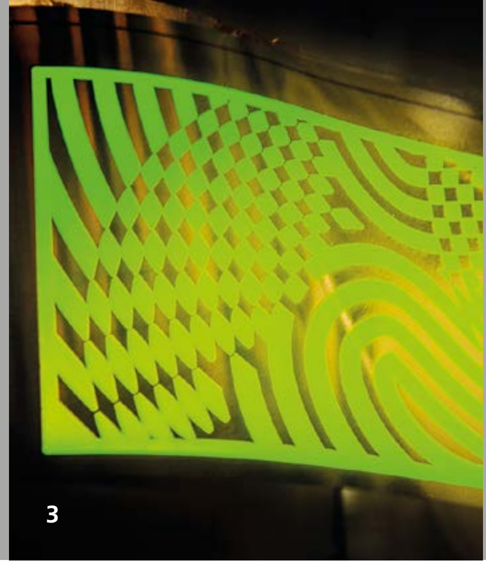
With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to re-inforce the competitive strength of the economy in their local region, and throughout Germany and Europe. They do so by promoting innovation, strengthening the technological base, improving the acceptance of new technologies, and helping to train the urgently needed future generation of scientists and engineers.

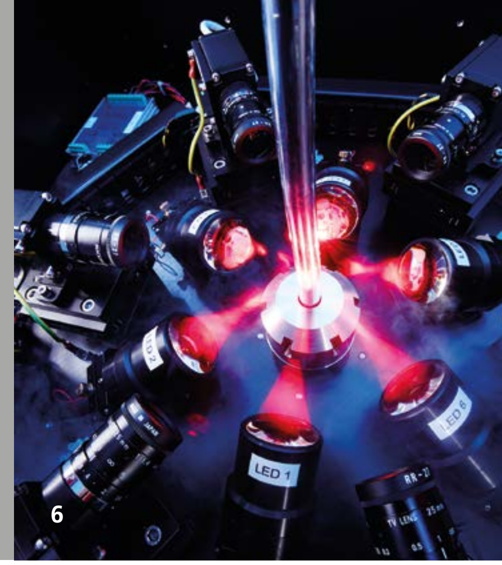
As an employer, the Fraunhofer-Gesellschaft offers its staff the opportunity to develop the professional and personal skills that will allow them to take up positions of responsibility within their institute, at universities, in industry and in society. Students who choose to work on projects at the Fraunhofer Institutes have excellent prospects of starting and developing a career in industry by virtue of the practical training and experience they have acquired.

The Fraunhofer-Gesellschaft is a recognized non-profit organization that takes its name from Joseph von Fraunhofer (1787–1826), the illustrious Munich researcher, inventor and entrepreneur.









FRAUNHOFER GROUP LIGHT & SURFACES

Competence by Networking
Six Fraunhofer institutes cooperate in the Fraunhofer Group Light & Surfaces. Co-ordinated competences allow quick and flexible alignment of research work on the requirements of different fields of application to answer actual and future challenges, especially in the fields of energy, environment, production, information and security. This market-oriented approach ensures an even wider range of services and creates synergetic effects for the benefit of our customers.

Core Competences of the Group

- Laser Manufacturing
- Beam Sources
- Metrology
- Medicine and Life Science
- Materials Technology
- Optical Systems and Optics Manufacturing
- Micro- and Nano Technologies
- Thin Film Technology
- Plasma Technology
- Electron Beam Technology
- EUV-Technology
- Process- and System Simulation

Fields of Application

- Automotive
- Biotechnology and Life Science
- Electronics and Sensors
- Energy and Environment
- Aerospace
- Mechanical and Plant Engineering, Tool Making
- Optics

Fraunhofer Institute for Applied Optics and Precision Engineering IOF[2]
The Fraunhofer IOF develops innovative optical systems to control light from the generation to the application. The service range covers the entire photonic process chain from optomechanical and opto-electrical system design to the manufacturing of customized solutions and prototypes. The institute works in the five business fields of Optical Components and Systems, Precision Engineering Components and Systems, Functional Surfaces and Layers, Photonic Sensors and Measuring Systems and Laser Technology.
www.iof.fraunhofer.de

Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP[3]
Fraunhofer Technology FEP works on innovative solutions in the fields of vacuum coating, surface treatment as well as organic semiconductors. The core competences electron beam technology, sputtering, plasma-activated deposition and high-rate PECVD as well as technologies for organic electronics and IC / system design provide a basis for these activities. Fraunhofer FEP continuously enhances them and makes them available to a wide range of industries: mechanical engineering, transport, biomedical engineering, architecture and preservation, packaging, environment and energy, optics, sensor technology and electronics as well as agriculture.
www.fep.fraunhofer.de

Fraunhofer Institute for Laser Technology ILT[4]
With more than 400 patents since 1985 the Fraunhofer Institute for Laser Technology ILT develops innovative laser beam sources, laser technologies, and laser systems for its partners from the industry. The technology areas cover the following topics: laser and optics, medical technology and biophotonics, laser measurement technology and laser material processing. This includes laser cutting, caving, drilling, welding and soldering as well as surface treatment, micro processing and rapid manufacturing. Furthermore, the Fraunhofer ILT is engaged in laser plant technology, process control, modeling as well as in the entire system technology. | www.ilt.fraunhofer.de

Fraunhofer Institute for Surface Engineering and Thin Films IST[5]
As an innovative R&D partner the Fraunhofer IST offers complete solutions in surface engineering which are developed in cooperation with customers from industry and research. The IST's "product" is the surface, optimized by modification, patterning, and/or coating for applications in the business units mechanical engineering, tools and automotive technology, aerospace, energy and electronics, optics, and also life science and ecology. The extensive experience of the Fraunhofer IST with thin film deposition and film applications is complemented by excellent capabilities in surface analysis and in simulating vacuum-based processes. | www.ist.fraunhofer.de

Fraunhofer Institute for Physical Measurement Techniques IPM[6]
The Fraunhofer IPM develops tailor-made measuring techniques, systems and materials for industry. In this way the institute enables their customers to minimize the use of energy and resources while at the same time maximizing quality and reliability. Fraunhofer IPM makes processes more ecological and at the same time more economical. Many years of experience with optical technologies and functional materials form the basis for high-tech solutions in the fields of production control, materials characterization and testing, object and shape detection, gas and process technology as well as functional materials and systems.
www.ipm.fraunhofer.de

Fraunhofer Institute for Material and Beam Technology IWS[1]
The Fraunhofer Institute for Material and Beam Technology is known for its innovations in the business units joining and cutting as well as in the surface and coating technology. Across all business units our interdisciplinary topics include energy storage systems, energy efficiency, additive manufacturing, lightweight construction and big data. Our special feature is the expertise of our scientists in combining the profound know-how in materials engineering with the extensive experience in developing system technologies. Every year, numerous solutions with regard to laser material processing and coating technology have been developed and have found their way into industrial applications. | www.iws.fraunhofer.de

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SUPPORTING AND TRAINING YOUNG SCIENTISTS AT THE FRAUNHOFER IST

Youth development – for the Fraunhofer Institute for Surface Engineering and Thin Films IST this means being active not only as a trainer and in an universitary setting, but also to introduce young people to scientific topics, to take away their fear of contact and to attract them to industry-related research. The promotion and supervision of pupils and students, who are interested in the research activities of the Fraunhofer IST, was again an important part of the institutes work in the year 2017.

Visit of the TU Braunschweig's "Technikantinnen"
Braunschweig, January 12, 2017. This year, 16 "Technikantinnen" of the TU Braunschweig visited the Fraunhofer IST for the first time in the framework of a project of the Lower Saxony technical center. The aim of the project is to give young female high school graduates an insight into the everyday life of a technical and scientific research institution. During their visit the young women were also introduced to the entry and employment opportunities at the Fraunhofer IST.

Bona SZ vocational training fair
Braunschweig, March 9 – 10, 2017. This year, the Fraunhofer Institute for Surface Engineering and Thin Films IST was represented at the BONA SZ vocational training fair already for the second time. Interested pupils could find out about the various professional training programs at the Fraunhofer IST over two days: from the administrative employee to the surface coater, to the physics laboratory technicians. Four trainees from the institute reported to the interested visitors about the everyday working life of physics laboratory technicians.

IGS Lengede's visit at the Fraunhofer IST
Braunschweig, March 23, 2017. This year, pupils of the IGS Lengede visited the Fraunhofer IST for the first time. The young people of the 12th and 13th grade have chosen the profile "Life Science", which primarily focuses on scientific contexts. After a brief introduction about the institute, they were given a presentation about surface technology and got to know various fields of application. During the following lab tour the group of pupils could get their own idea of working in a research institute.

Apprenticeship fair in the EINTRACHT stadium
Braunschweig, March 29, 2017. For the first time the Fraunhofer IST was represented at this year's apprenticeship fair of the Chamber of Commerce and Industry Braunschweig. In the business rooms of the Braunschweig stadium the young people had the opportunity to get informed about the institute and the different training opportunities at the Fraunhofer IST, from the education as physics laboratory technicians to the profession of a surface coater to an education in the commercial field.

Future day for boys and girls at the Fraunhofer IST
Braunschweig, April 27, 2017. Traditionally the Fraunhofer IST opened its doors in collaboration with the Fraunhofer WKI for 13 boys and 11 girls who had the opportunity to look behind the scenes of the two research institutes at the "Future Day". Wearing lab coats and protective goggles the young researchers moved through the institute past huge coating systems, yellow rooms and "mini thunderstorms" with plasma flashes. Finally, the pupils from grade five to seven had the opportunity to take part in various join-in-activities, e. g. by pretreating plastic cars with atmospheric pressure plasmas and subsequently metallizing them electroless with copper. At the end of the day the kids were allowed to take their coated works home with them.

1 *During their visit at the Fraunhofer IST the "Technikantinnen" of the TU Braunschweig gained an impression of the work at a research institute and even performed some experiments themselves.*

2 *The booth of the Fraunhofer IST at the BONA SZ vocational training fair: Future physics laboratory technicians of the Fraunhofer IST presented their vocational training program to the visiting students.*

3 *The participants of the "Future day for boys and girls" testing flame coloration at the Fraunhofer IST.*

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THE NETWORK OF COMPETENCE INDUSTRIAL PLASMA SURFACE TECHNOLOGY E. V. – INPLAS

The INPLAS e. V. Network of Competence, which is accredited as a network at the Federal Ministry of Economic Affairs (BMWi) in the "go-cluster" program has its administrative office at the Fraunhofer IST. Currently the network has 52 members from industry and science. Approx. 200 persons, 75 percent of whom are from industry participate in the network activities.

The objective of the network is to make plasma engineering better known and to support, promote, and moderate development in the numerous application areas in their respective complexity. Several highlights of the many activities, projects, and events in 2017 are presented in the section below:

12th INPLAS general meeting at Schneider GmbH & Co. KG | W&L Coating Systems GmbH

The 12th INPLAS General Meeting was held on November 20, 2017 at Schneider GmbH & Co. KG in Fronhausen. In addition to the formalities the meeting is always an important gathering of members for discussion of future network activities and inclusion of the opinions of the members, i. e. to promote the exchange of ideas. This time future topics such as digitalization in surface engineering – Industry 4.0 – sensor systems, energy efficiency, energy accumulators, additive manufacturing, and health / hygiene / nutrition were discussed. These topics should be moved further forward in the working groups, executive board meetings, and political activities. The accompanying factory tour gave the participants an interesting insight into the production of high precision and digitalized machine systems for precision optics and eyeglass lenses – an outstanding model for the implementation of production lines under the slogan "Industry 4.0".

INPLAS working groups

Starting this year the working group "Innovative Plasma Sources and Processes" is headed by the management team of Dr. Ulf Seyfert; Von Ardenne, Matthias Nestler; scia Systems GmbH, as well as Dr. Anke Hellmich; Applied Materials. Earlier this year the group met at scia systems in Chemnitz, the second meeting took place following the General Meeting in Fronhausen. Pretreatment, cleaning, and plasma sources were the main topics of the year.

The working group "Tool Coatings" under the direction of Hanno Paschke; DOC, Fraunhofer IST, met twice in Braunschweig at the Fraunhofer IST. The topics were plasma diffusion, low temperature treatments, the current "Öko-Clean" project, technology portfolio, as well as various new project approaches.

In the working group "Combined Surface Engineering" the current topic is additive manufacturing. There were various presentations and discussions at the meeting held in Venlo at the company Hauzer and at the Fraunhofer IST.

The working group "Plasma4Life" met in May at Erbe Elektromedizin GmbH in Tübingen to discuss the use of plasma technology in surgery, endoscopy and for development of test methods.

8th HIPIMS conference in Braunschweig

The 8th International Conference on High Power Impulse Magnetron Sputtering (HIPIMS) was held in 2017 in Braunschweig for the fourth time. In the Stadthalle Braunschweig the organizers welcomed 90 participants and 17 exhibitors from 19 countries worldwide. At this point INPLAS would again like to thank all sponsors, presenters, exhibitors, and participants, as well as the Conference Committee for their dedication and for coming.

37th Meeting of the industry working group (IAK) "Tool Coatings and Cutting materials"

With 40 participants the IAK is a popular forum for an exchanging insights and information with regard to the latest trends of tool manufacturers and users. The meeting takes place twice a year in Berlin and Braunschweig with partners, IWF of the TU Berlin, Fraunhofer IPK, Fraunhofer IST, and INPLAS e. V.

INPLAS TALKS: "Additive manufacturing meets surface engineering"

The objective of the event was to also show the possibilities and challenges of surface engineering for AM printed parts for plastics and for metals. In ten presentations and two workshops, various application examples were introduced and discussed. In the future the topics will be taken up in more detail in the working groups, in order to develop project approaches.

INPLAS series published in the technical journal VIP

Thanks to committed members and executive boards this year a 4-part INPLAS series "Vacuum in Research and Practice" was published with technical articles on the following topics: Cleaning, functionalizing, and coating – optimizing atmospheric pressure plasma products, 3D coatings, product costs for plasma processes, large area coatings.

INPLAS Network of Competence is awarded the Silver Label Certificate

On May 11, 2017 the re-assessment of the INPLAS Network of Competence took place. The innovation cluster demonstrated that selected quality indicators of the European Cluster Excellence Initiative are fulfilled and the cluster management organization, the processes, and instruments have been continuously further developed. INPLAS was certified through the European Secretariat for Cluster Analysis (ESCA) in cooperation with the Excellence Program "go-cluster" of the Federal Ministry for Economic Affairs and Industry.

Partial listing of other public relations projects or service projects

- Joint booth "Plasma and Laser Surface Technology" at the Hannover Messe
- 18th Symposium for Plasma Technology PT-18 in Göttingen
- Plasma Germany meetings and workshops
- Member service portfolio
- IP4Plasma, FAST, SafeWater, EU projects: responsible for the Work Package "Dissemination" or collaboration

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MEMBERSHIPS

Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik e. V.
www.awt-online.org

DECHEMA – Gesellschaft für Chemische Technik und Biotechnologie e. V.
www.dechema.de

Deutsche Forschungsgesellschaft für Oberflächenbehandlung e. V.
www.dfo-online.de

Deutsche Gesellschaft für Elektronenmikroskopie e. V.
www.dge-homepage.de

Deutsche Gesellschaft für Galvano- und Oberflächentechnik e. V.
www.dgo-online.de

Deutsche Gesellschaft für Materialkunde e. V.
www.dgm.de

Deutsche Glastechnische Gesellschaft (DGG)
www.hvg-dgg.de

Europäische Forschungsgesellschaft Dünne Schichten e. V. (EFDS)
www.efds.org

Fachverband Angewandte Photokatalyse
www.vdmi.de/deutsch/produkte/angewandte-photokatalyse.html

F.O.M Forschungsvereinigung Feinmechanik, Optik und Medizintechnik e. V.
www.forschung-fom.de

ForschungRegion Braunschweig e. V.
www.forschungregion-braunschweig.de

Forschungsgemeinschaft Werkzeug und Werkstoffe e. V. (FGW)
www.fgw.de

Forschungsvereinigung Räumliche Elektronische Baugruppen 3-D MID e. V.
www.3d-mid.de

Fraunhofer-Allianz Adaptronik
www.adaptronik.fraunhofer.de

Fraunhofer-Allianz autoMOBILproduktion
www.automobil.fraunhofer.de

Fraunhofer-Allianz Generative Fertigung
www.generativ.fraunhofer.de

Fraunhofer-Allianz Leichtbau
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Fraunhofer-Allianz Numerische Simulation von Produkten, Prozessen – www.nusim.fraunhofer.de

Fraunhofer-Allianz Photokatalyse
www.photokatalyse.fraunhofer.de

Fraunhofer-Allianz Reinigungstechnik
www.allianz-reinigungstechnik.de

Fraunhofer-Allianz Space
www.space.fraunhofer.de

Fraunhofer-Allianz SysWasser
www.syswasser.de

Fraunhofer-Allianz Textil
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Fraunhofer-Netzwerk Elektrochemie
www.elektrochemie.fraunhofer.de

Fraunhofer-Netzwerk Nachhaltigkeit
www.fraunhofer.de/de/ueber-fraunhofer/corporate-responsibility/governance/nachhaltigkeit/fraunhofer-netzwerk-nachhaltigkeit.html

Fraunhofer-Verbund Light & Surfaces
www.light-and-surfaces.fraunhofer.de

German Flatpanel Display Forum DFF
www.displayforum.de

German Water Partnership
www.germanwaterpartnership.de

Göttinger Research Council
www.uni-goettingen.de

International Council for Coatings on Glass e. V.
www.iccg.eu

Kompetenznetz Industrielle Plasma-Oberflächentechnik e. V. (INPLAS) – www.inplas.de

Materials Valley e. V.
www.materials-valley.de

Measurement Valley e. V.
www.measurement-valley.de

Nanotechnologie Kompetenzzentrum Ultrapräzise Oberflächenbearbeitung CC UPOB e. V.
www.upob.de

NANOfutures European Technology Integration and Innovation Platform (ETIP) in Nanotechnology
www.nanofutures.eu

PhotonicNet GmbH – Kompetenznetz Optische Technologien
www.photonicnet.de

Plasma Germany
www.plasmagermany.org

Spectaris – Verband der Hightech-Industrie
www.spectaris.de

Surface.net – Kompetenznetzwerk für Oberflächentechnik e. V.
www.netzwerk-surface.net

Wissens- und Innovations-Netzwerk Polymertechnik (WIP)
www.wip-kunststoffe.de

Zentrum für Mikroproduktion e. V. (ZeMPro)
www.microcompany.de

BOARD MEMBERSHIPS

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Gäbler, J.: European Technology Platform NANOfutures, Mitglied.

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Gerdes, H.: Society of Vacuum Coaters, Session Chairman.

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Keunecke, M.: Society of Vacuum Coaters, Dozent.

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Thomas, M.: Plasma Germany, Koordinierungsausschuss, Mitglied.

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Viöl, W.: DFG Fachkollegien, Mitglied.

Viöl, W.: Gesellschaft Deutscher Naturforscher und Ärzte e. V. GDNÄ, Mitglied im Fachbeirat.

Viöl, W.: HAWK Hochschule für angewandte Wissenschaft und Kunst Hildesheim/Holzminden/Göttingen, Vizepräsident für Forschung und Transfer.

Viöl, W.: Hochschulrektorenkonferenz Forschungskommission Fachhochschulen.

Viöl, W.: Kompetenznetz für Nachhaltige Holznutzung (NHN) e. V., Vorstandsmitglied.

Viöl, W.: Kompetenznetz Industrielle Plasma-Oberflächentechnik INPLAS e. V., Kassenwart.

Viöl. W.: Nationales Zentrum für Plasmamedizin, Vorstandsmitglied.

Viöl, W.: Spectaris – Verband der Hightech-Industrie, Fachverband Photonik, Mitglied des Lenkungsausschusses.

PUBLICATIONS

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