Bipolar plates of a redox flow battery.
FOREWORD

Ladies and gentlemen,

For the year 2012 we can once again report on many new results from research, interesting information, and recent developments from the Fraunhofer Institute for Surface Engineering and Thin Films IST

For our institute the year 2012 was another very successful year with many highlights and exciting projects. We provide you with a selection of project results on the following pages.

At this point may we direct your attention to the people whose hard work and commitment, trust and support forms the foundations for the success of our institute: above all the employees of the Fraunhofer IST, our partners from research and development, our customers from industry, our sponsors, colleagues and friends.

To them all we extend our very cordial thanks.

Prof. Dr. Günter Bräuer

Prof. (TUT) Wolfgang Diehl

[Images of the institute and signatures]
“Braunschweig technology transmitting from space” was the headline in the German press a few weeks ago. It was part of a report about the radar antenna - completed at the end of 2012 – of the Sentinel – 1a observation satellite which is scheduled to be shot into orbit at the end of this year. It will detect floods, forest fires, oil slicks at sea, changes in polar ice and even the movements of streams of refugees and send the corresponding data to earth. The components of the heart of Sentinel-1a, the 12 m long antenna, come from Braunschweig. The 600 waveguides manufactured by the local company Innovent and made of carbon-fiber-reinforced plastic (CFRP) were copper-plated in the Fraunhofer IST’s electroplating facility. This challenging project, commissioned by Astrium, a subsidiary of the aerospace concern EADS, represents a milestone in coating technology. Function testing at Friedrichshafen revealed a performance of the antenna which exceeded all expectations. If everything goes well, coatings from our institute will soon be leaving the earth for the first time ever.

July 3rd was a big day for both of the Braunschweig Fraunhofer institutes, the IST and the WKI. In the presence of the former science minister of Lower Saxony Prof. Johanna Wanka, the two presidents of the universities of applied science of Göttingen and Hannover, Prof. Christiane Dienel and Prof. Rosemarie Kerkow-Weil, as well as Prof. Ulrich Buller, senior vice-president for research planning at the Fraunhofer Society, the world’s first two Fraunhofer application centers were opened. With the application centers a particularly close collaboration between Fraunhofer and thematically related work groups in local technical engineering colleges will be institutionalized. For the Fraunhofer IST the establishment of the Fraunhofer Application Center for Plasma and Photonics means a logical extension of the existing collaboration with Prof. Wolfgang Viöl’s group at HAWK Göttingen. Here the emphasis is on the plasma treatment of organic surfaces ranging from wood to the human skin. Together with our own areas of competence, the Fraunhofer IST thereby seeks to establish itself in the promising field of ‘plasma medicine’. We take the opportunity of expressing our thanks to the Ministry of Science and Culture of Lower Saxony which will funding the application center with a total of 2.5 million euros over five years.

Another highpoint was the festive colloquium on November 29 during which the IST said farewell to Dr. Klaus Bewilogua, head of the “New tribological coatings” department, as he entered upon retirement. Nearly 100 persons attended, including not only the scientist’s family but also numerous colleagues, friends and associates. Dr. Klaus Bewilogua is regarded as a world expert on diamond-like carbon and cubic boron nitride coatings and worked at the Fraunhofer IST since its foundation.

As always we should like to show you in the following pages some selected results from an interesting year’s work. We owe our success above all to our clients in industry and our funders as well as to our outstanding employees. We look forward in 2013 as well to tackling many demanding challenges in surface technology and developing solutions.
**PRIZES AND AWARDS IN 2012**

**Fraunhofer medal for special services**  
Prof. Dr. Günter Bräuer, director of the Fraunhofer Institute for Surface Engineering and Thin Films IST and holder of the Chair of Surface Technology at the Technical University of Braunschweig, has been awarded the Fraunhofer Medal by the Fraunhofer Society. In the presence of the science minister of Lower Saxony, Prof. Dr. Johanna Wanka, he was presented at the Fraunhofer IST with the award for his special services to the Fraunhofer Society by Prof. Dr. Ulrich Buller, senior vice-president for research planning at the Fraunhofer Society following celebration of the founding of the country’s first Fraunhofer application centers.

"A life for thin films"  
For his engagement in the field of thin films Prof. (TUT) Wolfgang Diehl, acting director of the Fraunhofer IST, was honored at the 10th symposium of European vacuum coaters in Anzio, Italy. For a number of years now individuals in the field of surface engineering and thin films who have dedicated their careers to the triad of research, life and art have been awarded the prize “A life for thin films”. Before Prof. (TUT) Diehl this accolade has gone to Angus Macleod, Prof. Hans Pulker and Donald M. Mattox for their life’s work.

Double honor: Austrian Umdasch Prize and the Göttingen District Innovation Prize  
“Plasma treatment of wood” – for this entirely new approach the new director of the Fraunhofer IST Application Center for Plasma and Photonics Prof. Dr. Wolfgang Viöl has been awarded the 2012 Josef Umdasch Research Prize in Vienna. This award stands for outstanding performance in the field of forestry and wood sciences – and for this he was also given the Special Science Award of the Göttingen District Innovation Prize in 2012.

1st and 2nd ICCG9 poster prizes  
Two doctoral candidates of the Fraunhofer IST have been simultaneously awarded poster prizes for the results of their research and their successful presentations at the Ninth International Conference on Coatings on Glass and Plastics in Breda. Wilma Dewald won first prize for her poster “Optical evaluation of textured TCOs for a-Si:H/µc-Si:H thin film solar cells by angular resolved light-scattering measurements”. The second prize went to the Fraunhofer IST as well: Weyna Boentoro won this prize for her scientific presentation on the subject of “Multilayer design of durable UV- and scratch-protective coating on polycarbonate”.

“2012 SVC Best Poster Prize”  
At the annual Society of Vacuum Coaters SVC conference held each year in the USA, Christina Schulz, a doctoral candidate at the Fraunhofer IST in the “Optical functional coatings” department, won first prize for her poster “Process development for sputtering of p-type conducting Cu-Al-O mixtures”. The poster showed an entire process for producing p-TCOs and from the points of view of “science, style/presentation, clarity and relationship to vacuum research” was singled out as the best poster of the conference.

Heinrich Büssing Prize 2012  
Dr. Benedikt Michel, a former employee of the Institute for Surface Engineering IOT, the partner institute of the Fraunhofer IST at the Technical University of Braunschweig, has been honored with the 2012 Heinrich Büssing Prize for his research work into the “physicochemical properties of SiO2 coatings on plasma-treated silicon surfaces”. The subject of “low-temperature wafer bonding” is an extremely topical one in international research and development. Scientists from the Fraunhofer IST in collaboration with the SÜSS MicroTec company have already succeeded in making activation with atmospheric-pressure plasma possible.

1 Prof. Ulrich Buller presents Prof. Günter Bräuer, director of the Fraunhofer IST, with the Fraunhofer Medal.

2 Personal accolade: Prof. (TUT) Wolfgang Diehl receives the “A life for thin films” prize for his lifetime achievements.
Nowadays many innovative products require the use of plasma technology in at least one of the steps involved in their production. As tools for creating high-quality thin films, low-pressure plasmas are becoming increasingly important, not least in the light of current discussions about the use of renewable energies and efficient energy utilization. Photovoltaics and solar thermal technology cannot function without thin-film technology and the windows of the low-energy house demand transparent thermal insulation. If electromobility is really going to gain an appreciable market share, new challenges await which can only be overcome with coating technology.

With its research and development centers in the field of plasma technology and its applications for surface modification and coating, Germany is the worldwide leader. Not only universities and the INP Greifswald have contributed to this but also the Fraunhofer Institute for Surface Engineering and Thin Films IST. A further important milestone was reached at the Fraunhofer IST in the summer of 2012. As part of a collaboration with the University of Applied Sciences and Arts (HAWK) in Göttingen, the Fraunhofer Application Center for Plasma and Photonics (APP) was established with the primary task of carrying out research into atmospheric plasmas and their effect on organic surfaces from wood to human skin. This opens up entirely new prospects for individuals suffering from skin and nail diseases: a plasma beam from a handheld device can alleviate the symptoms of neurodermatitis or can heal onychomycosis. Not long ago the application center presented a "plasma comb" with which head lice could be successfully tackled while at the IST mother institute a "plasma in bags" was ignited to modify the inside of sterile cell culture bags and thus improve the cultivation of stem cells. Another innovative field of application, "plasma medicine", is therefore on the advance and we may well look forward to seeing what it will offer us in the future.

As part of its project sponsorship activities, the Federal Ministry of Education and Research has over the last three decades continuously funded work on plasma and thin-film technology. This support is currently being continued as part of the "Photonic research in Germany: optical technologies" program. I wish the Fraunhofer IST and its new application center every success with further innovations.
Space travel calls for high-performance materials. They must be extremely light while at the same time satisfying the high mechanical requirements associated with this form of travel. Extreme mechanical loads occur particularly when a rocket is launched. Although some operational functions are only needed once, they must still be absolutely dependable. Failures as a rule have catastrophic consequences and cannot be corrected in a rocket out in space. Carbon-fiber-reinforced plastics (CFRP) combine lightness and stability and are therefore of great interest to space travel.

For the ESA project Sentinel, a satellite program for environmental monitoring, the Fraunhofer IST, INVENT GmbH (a Braunschweig-based company) and Astrium GmbH have developed a process for metallizing CFRP antennae. The technical challenge here was to secure:

1. An absolutely flawless electrodeposited coating on the interior of the CFRP waveguide, and
2. Adhesion of the CFRP metallization in the -200 °C to +100 °C temperature range.

Requirements of this kind can only be satisfied by achieving an optimal mutual adjustment of the various coating techniques and materials. With the development of the metallization process the Fraunhofer IST has made a major contribution to the great success of the project.

At this point I should also like to stress the outstandingly good, trusting and smooth-running collaboration between the project partners.

Dr. Mathias von Alberti
Astrium GmbH

1 Simulation of the Sentinel 1a environmental satellite.
2 Just under 600 individually metallized CFRP waveguides are assembled at Astrium GmbH to form the radar antenna system for Sentinel 1a.
3 Astrium GmbH acknowledged the professional finish of the antennae with an internal award on the part of the project partners.
4 The Astrium team from left to right: Catherine Haas, Mathias von Alberti, Matthias Funke, Stephen Fährmann, Gabriele Danzer and Andreas Leupolz.
INSTITUTE PROFILE

As an industry oriented R&D service center, the Fraunhofer Institute for Surface Engineering and Thin Films IST is pooling competencies in the areas film deposition, coating application, film characterization, and surface analysis. A large number of scientists, engineers, and technicians are busily working to provide various types of surfaces with new or improved functions and, as a result, help create innovative marketable products. At present, the institute’s business segments are:

- Mechanical and Automotive Engineering
- Aerospace
- Tools
- Energy, Glass, Facade
- Optics, Information, Communication
- Life Science and Ecology

In pursuing these business segments the institute utilizes its competencies in the following fields:

- Friction Reduction and Wear Protection
- Super-hard Coatings
- Low Pressure Processes
- Simulation
- Atmospheric Pressure Processes
- Electrical and Optical Coatings
- Micro and Nano Technology
- Analysis and Testing

In line with the cross-sectional character of coatings and surface technologies the institute cooperates with a large number of coating service providers, equipment manufacturers, and coating users from diverse industries like machinery, transportation, production technology, electronics, optics, information technology, energy, medical devices, and biotechnology to name just the most important ones.

On an office and laboratory area of more than 4000 square meters 112 tenured employees are addressing a variety of research projects. Its capabilities are supplemented by the competencies of other institutes from the Fraunhofer Group “Light & Surfaces”. Many projects are supported by funding through the state (Land) Niedersachsen (Lower Saxony), the federal government, the European Union, and other institutions.

Important goals of the Fraunhofer IST are:

- the rapid transfer of innovative solutions from application oriented research and development to the industrial praxis,
- the establishment of new future oriented technologies in the market place and
- the transfer of these innovative technologies to small and medium sized companies.
Talent management
In 2012, the period under review, the institute had 112 employees. Around 50% 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 by five employees in all.

Operating budget
In the period under review operating expenses ran to a total of €11.6 million. Here personnel costs amounted to €7.3 million and materials expenditure to €4.3 million. This corresponds to an almost ideal 60:40 ratio of personnel and material-related costs.

Earnings structure
With revenues from industry amounting to almost €4.7 million, the relative increase was 40.6%. With €2.6 million from public-sector revenues, total revenue was €7.3 million. Here as much as €500,000 derived from EU projects.

Investments
Some €360K was dispensed on normal investment in 2012, the period under review. This means for the Fraunhofer IST an overall budget (B+I) totaling €12 million.
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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

COATING

We develop processes and coating systems
Thin films are the core business of the Fraunhofer IST. The institute utilizes a wide range of coating technologies, ranging from plasma assisted deposition in vacuum and at atmospheric pressure over hot-filament CVD processes to electroplating.

Our services are:
- Development of coatings
- Process technology, including process diagnostics, modeling and control
- Simulation of layer systems and processes
- Development of plant components and processes

TESTING / CHARACTERIZATION

We ensure quality
A fast and reliable analysis and quality control is the prerequisite for a successful coating development. We offer our customers:
- Mechanical, chemical, micromorphological, and structural characterization
- Test methods and product specific quality control methods, e.g. wear measurement on arbitrary parts
- Adhesion test methods
- Optical and electrical characterization
- Rapid and confidential failure analysis
- Testing of corrosion resistance

APPLICATION

We transfer research results to 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 (RXRF)
- X-ray diffractometer (XRD, XRR)

Microscopy
- Scanning electron microscope (SEM)
- Confocal laser microscope (CLM)
- Scanning tunnel and atomic force microscope (STM, AFM)
- FTIR microscope
- A variety of optical microscopes

Measurement of friction, wear and corrosion
- Pin on disk tester
- Ball-cratering test (Cals)
- Wazau high-load tribometer (in air, in oil)
- CETR high-temperature tribometer (in air, in oil)
- Print roller tribometer (in air, in oil)
- Taber abraser test, abrasion test, sand trickling test
- Microtribology (Hystron)
- Impact and fatigue tester (Zwick Pulsator)
- Salt spray test, environmental tests

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 spectrometer
- Ellipsometer
- Colorimetry
- Angular-resolved scattered light measurement (ARS)
- FTIR spectrometer
- FTIR microscope

Plasma diagnostics
- Absorption spectroscopy
- Photoacoustic diagnostics
- LIB – laser induced fluorescence
- High-speed imaging
- Optical emission spectroscopy OES
- Electron energy distribution function
- Fiber thermometry
- Electrical performance test
- Numerical modeling

Spezialisierte Messplätze
- Characterization of solar cells
- Measuring station for photocatalytic activity
- Contact angle measurement (surface energy)
- Measuring systems for electrical and magnetic coating properties
- Test systems for electrochemical wastewater treatment
- Measuring stations for the characterization of piezoresistive sensor behavior
- Biochip reader for fluorescence analysis
SPECIAL EQUIPMENT

- a-C:H:Me, a-C:H, hard coating production plant (up to 3 m³ 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 x 100 cm²)
- Industrial scale HIPIMS technology
- PVD coating plant (electron beam and thermal)
- Plants for plasma diffusion
- Coating systems for hollow cathode processes
- Coating plant for thermal and plasma atomic layer deposition (ALD)
- Hot-filament-CVD units for crystalline diamond coatings (up to 50 x 100 cm²)
- Hot-filament-CVD unit for silicon-based coatings (up to 50 x 60 cm²)
- 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 0 x 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
- Machine for internal coating of bags or bottles

- Laser for 2D and 3D microstructuring
- 2 mask aligner for photolithographic structuring
- Laboratory for microstructuring (40 m² clean room)
- Equipment for electroplating processes
- 15-stage cleaning unit for surface cleaning on aqueous basis
- Clean room – large area coating (25 m²)
- Clean room – sensor technology (35 m²)
- Mobile atmospheric pressure plasma sources
- Nanosecond dye laser (Nd:YAG-Laser)
- CO₂-laser and Excimer-Laser
- EUV spectroscopy
SUSTAINABILITY

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 for a number of years now been developing solutions for sustainable products and sustainable industrial production.

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:

- **Alternative materials**
  - Since the mid-1990s intensive research has been in progress at the Fraunhofer IST on replacing indium tin oxide (ITO) with alternative materials such as ones based on ZnO and SnO2 and TiO2.
  - Thin films for LEDs based on oxides instead of GaN manage without color conversion by luminescence of rare earths.
  - At the Fraunhofer IST alternative materials are being developed for the high-refractive-index tantalum oxides used in high-precision optics.

- **Material efficiency**
  - With an additive galvanic metallization process, metals such as copper, for example, are applied to selected areas.
  - Working materials with new properties are being found by combining different materials.

- **Production efficiency**
  - Optimized hard-material and nanostructured coating systems for forming or cutting tools increase service lives 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.

- **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 or water without using disinfectant agents.
  - The functionalization of surfaces in plasma enables adhesive to be dispensed with when, 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.

- **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.
  - Robust thin-film sensor systems in highly stressed parts of components increase reliability and safety in many fields of application, such as, for example, electromobility or wind power plants.
THIN FILMS FOR ELECTRICAL STORAGE DEVICES AND CONVERTERS

Electrical storage devices, such as, for example, lithium-ion batteries, and even converters, such as the fuel cell, make high and often contradictory demands on the materials used. In addition, the materials which satisfy these requirements are very expensive and only suitable to a limited extent for quantity production. They lack long service lives, high performance or mechanical stability. For this reason it is primarily economic aspects which drive forward the search for new materials and designs. A variety of possible solutions for different applications are available at the Fraunhofer IST.

In all current material concepts in the field of electrical storage devices and converters an important rôle is played by the surface properties of electrodes, conductor foils or bipolar plates. To secure the longest possible service life the surfaces must have a number of different properties:

- A low electrical resistance so as to limit electrical losses in the system, and
- A good corrosion stability with respect to aggressive electrolyte media.

Although graphitic materials are used particularly often on account of their high chemical resistance, they only have low mechanical strength. They need to be really thick in construction and for mobile systems this means unacceptably high installation volumes. Metallic systems are more suitable. These have not only very good electrical conductivity but also very high strength and can be produced considerably less expensively. The sole disadvantage of metallic materials is that due to formation of their native oxides they usually have a really high surface resistance, especially when the metal is very corrosion-resistant, such as is the case with stainless steel, for example. The key here is to use the thinnest coatings or surface modifications. At the Fraunhofer IST, the electrical resistance and corrosion protection of metallic electrodes or bipolar plates can be configured using a wide range of different processes, including

- PVD or plasma diffusion processes,
- CVD processes,
- Atomic layer deposition (ALD) and
- Atmospheric plasmas.

Fuel cells

Metallic bipolar plates offer considerable advantages for fuel cells in automotive applications. Even thin plates are mechanically stable. Furthermore, complex gas ducts can be fabricated inexpensively by means of a simple forming process. The Fraunhofer IST has been working for years on the optimization of metallic bipolar plates. In addition to coating with hard material or carbon-based layers, the plasma nitriding of stainless steels in particular is being further developed. The goal of this development work is a treatment method which will be both inexpensive and suitable for quantity production.

Lithium-ion batteries

In lithium-ion batteries, metals, in most cases aluminum and copper, are used as conductor foils on both electrode ends. These two metals are corrosively attacked so strongly by the electrolytes that internal resistance is raised and the connection to the electrode materials weakened. In close collaboration with various material suppliers, plant manufacturers and battery producers, the Fraunhofer IST is researching into improving these material transitions by means of plasma treatments and coatings. The aim is to improve electrical and chemical properties and make large-scale production possible. In addition, the institute has the expertise necessary for enhancing the electrode materials so as to increase cyclic durability, for example.

Redox flow batteries

Redox flow batteries make similar demands on bipolar plate as do fuel cells. Here, too, the lowest transition resistances and a high resistance to corrosively aggressive liquid electrolytes are major requirements. Metal-doped carbon coatings offer a variety of possibilities for securing an optimal design for contact surfaces. The Fraunhofer IST is working together with the Fraunhofer ICT on innovative solutions for optimized redox flow batteries. One of these may be seen on pages 64–65.

Thin-film batteries

Thin-film batteries are of great interest for the stand-alone operation of sensor systems, for example. Although electrical storage systems made entirely by thin-film technology only have a low storage capacity they can nevertheless even be fitted to curved surfaces and only take up very little installation space. Here the Fraunhofer IST is developing application-specific solutions.
The business area "Mechanical and Automotive Engineering" has been developing coating systems and surface technologies that reduce friction, protect against wear and corrosion and that are optimized according to the application. In addition to modifying coatings to suit special applications as well as the development of new coating systems, the development and implementation of product- and production-adapted coating processes stands in the foreground. Examples are:

- Application-adapted carbon-film systems (DLC) for internal combustion engine components
- DLC coatings with high thermal stability
- Smart washers
- Sensor coatings for components and tools
- New duplex systems for highly stressed components
- Coating systems for the self-sharpening of industrial cutting applications

Customers of this business division include not only coating service companies but above all coating users from all areas of machine manufacturing and the automotive industry.

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SAVING RESOURCES IN THE INTERNAL COMBUSTION ENGINE

Fraunhofer’s internal project “TriboMan – Production-integrated reduction of friction and wear in internal combustion engines” is a research project aimed at reducing friction and comes under the umbrella of the Fraunhofer futures topic of “green powertrain technologies”. To secure a permanent reduction in friction and wear, running-in processes and the formation of tribologically effective outer layers are anticipated by new aluminum alloys, production, machining, structuring and coating processes and integrated into manufacturing.

Competence in engineering fields and collaboration between technical disciplines

In close collaboration with four other Fraunhofer institutes – the IWU, IWM, IFAM – the Fraunhofer IST is jointly working on cross-disciplinary solutions for critical points of friction in modern internal combustion engines.

Friction reduction by means of chromium-rich carbon film systems

The main areas of research at the Fraunhofer IST lie in the development, tailoring and optimization of wear-resistant, hard and antifrictional coating systems with respect to favorable running-in behavior and optimum lubricant interaction. Carbon film systems which contain chromium (a-C:H:Cr) are predestined for this application on account of their very attractive properties, such as, for example, extreme chemical resistance, high heat resistance, great hardness, high wear resistance and low coefficients of friction.

Results

Wettability and hardness can be improved by increasing the chromium content. The additional incorporation of iron also has a positive effect on wettability. The high chromium content of about 70% results in an almost 30% reduction in the contact angle as a measure of wettability as compared with an uncoated specimen. The hardness of the a-C:H:Cr coating can be increased by up to about 60%. In the pin-and-disk test and the rolling element test the friction and wear properties of chromium-rich carbon film systems are being investigated on the basis of generalized frictional processes. A reduction in the coefficient of friction coupled with simultaneous lower wear was obtained with all coatings not only in the pin-and-disk test but also in the rolling-element test. Here highly doped coating variants (50–60 % chromium content) came out especially well. The volume of wear can be almost halved by the incorporation of 60 % chromium. These coatings are of particular interest for engine applications. In conjunction with the results from the other project partners they are arousing great expectations as regards engine test bed measurements.

Outlook

In oil-lubricated tribological tests, chromium carbon coatings exhibit outstanding frictional and wear properties. The coatings can be tailored to any service conditions via the coating structure and its composition.

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INTERACTION OF DLC COATINGS WITH ENGINE OILS

Hydrogenated diamond-like carbon coatings (DLCs) are used in a large number of variants for reducing friction and wear. Here carbon-based coatings stand out on account of their excellent property combinations of low coefficients of friction, high hardness and wear resistance as well as chemical resistance. Thanks to these properties DLC coatings have been used for years in large-scale production by the automotive industry. As part of a development project in conjunction with the Oerlikon Balzers company, the interaction of DLC coatings with certain oil additives has been investigated at the Fraunhofer IST and CrC/a-C:H coating systems with improved performance developed.

The trend towards ever higher power densities in internal combustion engines coupled with the simultaneous demand for reduced fuel consumption and emissions means higher and higher contact pressures and thus a more frequent occurrence of boundary and mixed friction with lubricated tribological pairs. This development places greater demands not only on the wear resistance of the coating but also on a positive interaction of the coating with oils and their additives.

DLC coatings in tribological high-load areas with additive-enhanced oil lubrication

DLC coatings are in principle suitable for making improvements in tribological behavior possible not only in unlubricated but also in lubricated applications. They are however not designed for optimum interaction with additives. Test results with oil-lubricated highly stressed tribological systems have revealed that carbon coatings containing metal (Me-DLC) have interactions with additives which pure DLC do not. They show chemical reactions with complex-forming additives, such as, for example, MoDTC (molybdenum dithiocarbamate) and make it possible for friction-reducing Mo sulfides and Mo oxides to form.

DLC and CrC/aC:H coatings

Although pure DLC coatings (> 25 GPa) are considerably harder than Me-DLC with 10–15 GPa, DLC coatings in the highly stressed mixed-friction range exhibit continuous wear in the presence of MoDTC (Fig. 1). The Me-DLC coatings usually available on the market cannot offer sufficient performance under these extreme conditions. One challenge in coating and process development was to ensure positive interactions with additives while at the same time to secure a marked increase in wear resistance. A special CrC/a-C:H functional coating has been developed and characterized as a capable solution for this complex requirement profile combining a low coefficient of friction and high wear resistance in the presence of oils containing MoDTC (Figs. 2 and 3). Considerable assistance was provided during development by coating characterization methods and laboratory tests such as the pin-on-disk test under defined oil-lubricated tribological conditions and the analytic assessment and evaluation which followed.

Application tests and summary

In close-to-application engine test bed testing the CrC/a-C:H coatings which had been developed confirmed the laboratory results. In addition a further contribution to friction reduction emerged in the tribological systems under consideration. Coating processes for various coating installations have been developed. The CrC/a-C:H coatings are powerful, improved alternatives to the industrially established DLC coatings in highly stressed tribological systems with additive-enhanced oil lubrication.

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![Fracture photomicrograph of a DLC coating with wear.](image1)

![SEM micrograph of the friction track of a CrC/a-C:H coating.](image2)

![EDX micrograph of the friction track (C green, Mo red).](image3)

![Coefficients of friction and the friction track depth of CrC/a-C:H coatings in the pin-on-disk test with oil lubrication with MoDTC additive.](chart)

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SILICON-DLC COATINGS WITH HIGH THERMAL STABILITY

Hydrogenated diamond-like carbon coatings (a-C:H or DLC) have very low coefficients of friction, are hard and wear-resistant as well as chemically inert. A major disadvantage of these coatings is their limited thermal stability which, with ever greater loads on tribological pairs – as in engines, for example – has an increasingly negative effect. As part of a development project in conjunction with AMG Coating Technologies, silicon-containing DLC (Si-DLC) and DLC nanolayer coating systems have been developed which are considerably more thermally stable than DLC (a-C:H).

Magnetron sputtering instead of PACVD

Silicon-DLC coatings with silicon contents of around 20 atom %, which are known for their particularly low coefficients of dry friction, are produced in industry almost exclusively by PACVD processes (plasma-assisted chemical vapor deposition). Here vaporous starting materials, such as, for example, TMS (Si(CH₃)₄), are used which dissociate and are ionized in the plasma. The coatings thus deposited have relatively high concentrations of hydrogen (> 20 atom %). At the Fraunhofer IST the coatings were deposited by a reactive sputtering technique using graphite and silicon carbide targets and acetylene as the reactive gas with the aim of lowering the hydrogen concentrations and improving the thermal properties. By varying the process parameters appropriately, the composition of the coatings could be specifically adjusted. Pure DLC coatings could only be produced using the graphite targets and sputtering method described. Metallic interlayers markedly improved the adhesion of the coatings, especially on steel substrates.

Coating characterization

Both the Si-DLC and the DLC coatings were amorphous, compact and homogeneous. A dimpled surface is typical of very hard coatings (Fig. 1).

<table>
<thead>
<tr>
<th>Comparison of DLC and Si-DLC coatings.</th>
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<tr>
<td>DLC coating</td>
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<td>Si-DLC nanolayer coating</td>
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<tr>
<td>Hydrogen content (atom%)</td>
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<tr>
<td>Hardness (nanohardness)</td>
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<td>&gt; 40 GPa</td>
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<td>Coefficient of dry friction (against steel) (at 20 atom % Si)</td>
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Thermal stability of the a-C:H:Si coatings

In order to assess their thermal stability the coatings were successively annealed in air; in each case for one hour at 200, 300, 400 and 500 °C and cooled down to room temperature after each conditioning step. It emerged that the hardnesses of all Si-DLC coatings tested actually still increased slightly up to the highest temperature while the coefficients of friction remained virtually constant (see diagram). With the DLC (a-C:H) coating on the other hand, both hardness and the coefficient of friction changed considerably above 400 °C.

Outlook

For highly stressed tribological pairs with relatively high thermal exposure, such as in combustion engines, the nanolayer coatings produced by sputtering which are described here could be an attractive alternative to the a-C:H coatings currently used and expand the area of application of carbon-based coatings.

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PIEZORESISTIVE THIN-FILM SENSOR SYSTEMS IN TOOL SPINDLES TO INCREASE MACHINE AND PROCESS RELIABILITY

In woodworking, cutting and feed rates are considerably higher than in metalworking and can, for example, amount to as much as 24,000 rpm in the case of high-speed cutting. In the event of a malfunction this high kinetic energy can lead to serious damage to the machine and entail a high safety risk to the operator. For this reason the development of a new kind of sensorized thin-film system as a measurement and monitoring system represents an important step in ensuring flexible, safe production which makes an efficient use of resources.

The sensorized thin-film system

The production of the sensorized thin-film system involves a large number of challenges. The coating system is directly applied to the contact face of a spindle 480 mm in length and weighing 7.3 kg (see Fig. 1). The basis of the sensorized thin-film system is the piezoresistive DiaForce® sensor coating. This is an amorphous hydrocarbon layer which changes its resistance in a defined manner under load. This property is exploited in the coating system to measure loads. The system is built up under conditions of electrical isolation such that first of all an electrical isolating layer 4 µm thick is homogeneously deposited on the component surface. Separate electrode structures made of chromium and measuring only 200 nm thick are then created by photolithography and wet-chemical etching. A piezoresistive DiaForce coating 1 µm thick is then applied homogeneously to this structured metal layer by a PACVD process. The final layer is an electrically insulating and wear-protection coating of SiCON® modified with silicon and oxygen (d = 1 µm). The challenge in these developments is not only the deposition of highly adhesive coatings with different functionalities but above all their photolithographic structuring.

Sensor properties of the thin-film system

The major advantage is that the sensorized thin-film system, which is only 8 µm thick, can detect loads with a very high resolution not only statically but also dynamically. This makes it ideal for measuring clamping forces and balance quality directly in the contact zone (contact surface) between the tool interface and the spindle shaft. The results of precharacterization testing carried out on the test stand with three sensor structures and applying normal force cycles revealed characteristic linear dependencies of sensor resistance on load. The change in resistance fell within the 3 ohm/N range. This behavior is reversible which means that when the load is removed the system reverts to its original resistance.

Outlook

During the further course of the project the change in the clamping force and the balance quality of the spindle shaft in rotational operation are to be investigated. To do so the sensorized thin-film system will be combined with a telemetry unit manufactured by Artsi GmbH and then tested. The aim is to transmit the measurement results by radio from the rotating spindle shaft to a stationary evaluation program.

These results were obtained in collaboration with the Institute for Machine Tools and Factory Management (IWF) of the Technical University of Braunschweig and the Fraunhofer IST. The joint research project is supported by funds from the German Federation of Industrial Research Associations (AiF) via the International Association for Technical Issues relating to Wood (iVTH).

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INTELLIGENT WASHER FOR MEASURING FORCES IN SCREWED CONNECTIONS

A new kind of intelligent washer is now being developed at the Fraunhofer IST: with piezoresistive thin-film sensor systems, forces and preloadings can be measured directly in screwed connections, doing so precisely, reliably, continuously, dynamically and via contactless RFID-transmission. Using these innovative face seals saves material and costs and leads to greater reliability, safety and efficiency – particularly in critical applications, such as in materials handling and power engineering.

How the sensorized thin-film system is produced

In the first step, the piezoresistive DiaForce® coating is deposited by the PACVD process on steel disks manufactured by Eilhauer Maschinenbau GmbH and which are polished on one side. In this application a homogeneous coating thickness of 6 µm is produced. Individual electrode structures made of chromium and measuring only 0.2 nm thick are then created by photolithography and wet-chemical etching. The washers at this stage of production can be seen in Figs. 1 and 2. An electrically isolating and wear-protecting coating 3 µm thick is deposited homogeneously on these structures. It consists of silicon- and oxygen-modified carbon. At the Institute of Transportation and Industrial Automation of the Leibniz University of Hannover, a transponder manufactured by Microsensys GmbH was mounted using conductive adhesive to enable data to be transmitted without using wires.

Potential for practical application

In mechanical engineering, screwed connections are often used which require a precisely defined preloading which will remain constant over the entire service life. In most cases the exact preloading is set by tightening up the screws with a specific torque. In this new method, however, frictions are also measured which are not immediately part of the preloading, such as, for example, the friction beneath the screw head and the friction in the thread. In addition, the relationship between torque and the preloading force in the screw is influenced by fluctuating friction ratios due to a dry or lubricated thread. These circumstances will normally result in screws being overdimensioned. If the pretensioning force is known precisely, considerable savings in weight and costs become possible in the case of dynamically stressed screwed connections, such as used for example in materials handling and energy production, the pretensioning force of the screws has to be checked periodically. Here too the torque wrench is mostly used. However the screw forces can only be checked at a standstill since the periodic torque inspection can also affect installation functions, such as, for example, the starting-up and braking behavior of belt conveyors. The advantage of the intelligent washer is that contactless measurement can be incorporated into the installation control system.

Safety-related applications

In the case of safety-related threaded connections, such as, for example, in wind power plants or reactors, there is currently no way of accurately documenting their state as regards forces. Although the readings of torque wrenches when tightening up or checking can be saved to data storage media, errors can arise when assigning the readings to the screws. The use of washer sensors makes securing screwed connections much easier and less time-consuming.

These results were obtained as part of the InUse (a German acronym standing for ‘intelligent washer for measuring forces in screwed connections’) project funded by the Federal Ministry of Economics and Technology on the basis of a resolution of the German Bundestag. The project consortium includes Eilhauer GmbH, Mikrosensys GmbH, the Institute of Transportation and Industrial Automation and the Fraunhofer Institute for Surface Engineering and Thin Films IST.

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CAPACITIVE THIN-FILM SENSOR SYSTEMS FOR FACE SEALS

In order to determine the gap distance as a function of process parameters in face seals made by EagleBurgmann Germany GmbH & Co KG, a sensorized thin-film system has been developed at the Fraunhofer IST which is applied directly to the surface of the face seal. Being able for the first time to measure these variables without interrupting operation is a major step in optimizing and verifying simulations and operating modes.

The capacitive coating system

In the first coating process an electrically isolating coating consisting of a silicon- and oxygen-modified hydrocarbon layer, also known as SiCON®, is homogeneously deposited on ceramic seal rings made by EagleBurgmann Germany GmbH & Co KG. A laser system is used to prepare contour masks which are adhesive on one side and these are applied manually to the coated surface at defined distances apart. A coating of chromium only 200 nm thick is then homogeneously applied by the PVD process to the masked surface of the ring. At the end of this lift-off process the masks are removed and the structures are left on the surface. Each individual structure can be regarded as a capacitor plate. What is special here is that the contacting areas are not on the top face but on the sloping inner face since it is only here that it is possible to locate soldered connections. Finally a coating of SiCON is once again laid down, this time as the top coating.

The principle behind capacitive measurement

A capacitor plate is created in the slide face of the stationary seal ring with the aid of a thin-film sensor system integrated into the surface. As can be seen from Figs. 1 and 2, several capacitor plates are accommodated on the seal ring. The other capacitor plate is the rotating counter-ring. The measured value of the capacity of a capacitor is a direct measurement of the plate separation. This in turn is directly related to the gap distance which is found when the seal is in operation. This means that it is possible to determine experimentally the gap width which results as a function of operating parameters such as speed and operating pressure. The diagram shows a graph of the gap distance determined by experiment plotted against a rising operating speed. Not only measured values are shown, but also the numerical values obtained as part of the design calculations (unbroken line). A very good correlation was achieved between experiment and numerical calculations.

Collaboration

The development of the capacitive thin-film sensor system for face seals manufactured by EagleBurgmann Germany GmbH & Co KG is an objective of the INTELLA (a German acronym for ‘intelligent, lightweight bearings and seals for automotive and mechanical engineering’) funded by the Federal Ministry of Education and Research and supervised by the project sponsors Jülich. Other project partners are Schaeffler Technologies GmbH & Co KG, Cerobear GmbH, KSB AG, ScienLab Electronic Systems GmbH and the Fraunhofer Institute for the Mechanics of Materials NWMT.

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REDUCTION OF FOULING BY MODIFIED DLC COATINGS

With the use of heat exchangers, especially in the chemical, pharmaceutical, and food industries, the problem of fouling often occurs. Examples are contaminations caused by crystallization, corrosion, or by chemical and biological reactions. Fouling leads to a considerable increase in thermal resistance and thus reduces the performance of the heat exchanger. In Germany, economic losses of several billion euros a year are caused by fouling. At the Fraunhofer IST, in close collaboration with the Institute for Chemical and Thermal Process Engineering (ICTV) of the Technische Universität Braunschweig, coatings based on modified diamond-like carbon (DLC) have been developed with which the effects of fouling can be drastically reduced.

Potential of modified DLC coatings
By integrating suitable elements such as silicon, oxygen, or fluorine, hydrogenous amorphous carbon coatings (a-C:H) can be modified in such a way that their surface energy decreases while their anti-adhesive effect is increased. The a-C:H:Si and a-C:H:Si:O coatings developed at the Fraunhofer IST were deposited with a thickness of about 3 μm via plasma-assisted chemical vapor deposition (PACVD). The fouling behavior of the coatings was then tested at the ICTV. Calcium sulfate (CaSO₄) was used as the model substance for the fouling experiments. The induction periods, i.e. the periods after which additional thermal resistance (fouling resistance) results from fouling, were compared in order to evaluate the fouling process. It was shown that it is possible to considerably extend the induction periods with modified DLC coatings in comparison to uncoated stainless steel. The modified DLC coatings proved to be particularly effective when a saline solution flowed across the surface. While the fouling resistance on an uncoated stainless steel surface increased after only a short time at a flow rate (w) of 0.15 m/s, the a-C:H:Si- and a-C:H:Si:O-coated surfaces remained almost unchanged (graph) and free of fouling (Fig. 2) even after several hundred hours of testing. In contrast, a thick film formed on the uncoated stainless steel surface (Fig. 1).

Application possibilities
Similar effects of DLC-coated surfaces have also been noted in the food industry, e.g. with whey protein deposits and cleaning. Combination treatments of surfaces, such as the coating of electropolished surfaces, have proven to be particularly promising. The high mechanical strength of the modified DLC coatings is a considerable advantage as they can withstand even intensive cleaning processes on the heat transfer surfaces without difficulty.

Outlook
Future coating developments for antifouling applications will, among other things, be oriented toward opening up new application fields and toward the internal coating of heat exchanger tubes of several meters in length. For operating temperatures over around 200 °C, alternative coating materials have to be developed.

1 CaSO₄ fouling film on an uncoated stainless steel sheet.
2 CaSO₄ fouling film on a stainless steel sheet coated with SICON®.

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In the »Aerospace« business field, processes and coatings are developed for special materials, such as lightweight materials, for which in many cases no established coating methods yet exist. The principle areas of application are wear and corrosion protection in aviation as well as optical and electrical functions in space travel. Currently the following areas are being tackled by the Fraunhofer IST:

- Galvanic metallization of CRP components
- Metallization of titanium components by process combinations
- Wear-protection coatings for aircraft jet engines
- Bearing sensor systems – condition monitoring in aircraft
- Development of surfaces for molds which do not use release agents
- Galvanic coating of magnesium for lightweight design in aircraft

Customers include companies in the aerospace industry and their suppliers.

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The piezoresistive thin-film system

The thin-film sensor system is built up in several steps:

- Firstly the piezoresistive sensor coating DiaForce® is deposited homogeneously over the steel base component by a PACVD process.
- In the next step, in order to create local measurement points, a chromium coating is deposited which is then structured by photolithography and wet-chemical etching.
- In the third step, a structured electrically isolating and wear-protecting coating is deposited which consists of a SiCON® hydrocarbon layer modified with silicon and oxygen.
- The coating system is completed by a further layer of chromium and a final SiCON® coating (Fig. 1).

The coating structure offers some useful properties for aviation applications. On the one hand the isolating layer between the electrode conductor and the DiaForce permits a free arrangement of the sensor structure in the pressure area without affecting the sensor resistance. On the other hand the geometry of the sensor can be optimally tailored to the application thanks to the new coating structure, which means that the course of the sensor signal can be influenced directly. This is not normally possible with other sensors.

Sensor systems for condition detection in primary flight control system actuators

Since, however, the loads in the rolling surfaces are so high that sensorized coatings would suffer wear before the actuator reached the service life limit required in aviation, a solution has been developed by the Fraunhofer IST in collaboration with the Institute of Flight Systems of the German Aerospace Center (DLR) in Braunschweig whereby a coating system is applied to the outer ring and outside the main load areas. Tests conducted at the DLR as part of the European project “More Open Electrical Technologies (MOET)” show that this innovative sensor system has the necessary sensitivity and suitability to be used for condition detection.

Current research work is focused on moving the sensor coating from the outer ring of the bearing to the adjacent surface of the bearing block while using dedicated sensor elements. These are located in the contact surface between the bearing ring and the bearing block which means that the sensor system can be reused after replacement of actuator components, thereby reducing operating costs.
CORROSION PROTECTION IN AVIATION

Extremely strict safety standards are required in the aerospace industry and yet some substances are still used which are prohibited by law in ordinary life. For example, anti-corrosion coatings can still be found in aircraft which contain chromium (VI) compounds or cadmium since no adequate substitute satisfying safety requirements has yet become available. According to REACH regulations* these materials are no longer permissible in automobile manufacturing. However even in the aerospace sector there is increasing pressure from the legislators and consumers to find substitutes for them.

Searching for a replacement
Although a number of good substitutes have been found for surfaces containing Cr(VI), development work on replacing cadmium as corrosion protection is still in its early stages. One quarter to about one third of the entire production of cadmium is still used as corrosion protection for iron and similar metals: even at a thickness of 8 µm cadmium coatings applied by electrolytic deposition or by vacuum deposition already provide protection against corrosion. In addition, cadmium has some favorable tribological properties as a low-friction coating. For this reason the Fraunhofer IST in conjunction with other research institutes is carrying out intensive research into technical solutions for replacing cadmium.

The technical solution
The galvanic deposition of aluminum from so-called ionic liquids as a cadmium substitute has already been researched for some time now. Unfortunately all of the aluminum salts and corresponding electrolytes so far known and used are extremely sensitive to moisture which resulted in the need to conduct most laboratory experiments into the galvanic deposition of aluminum in a glove box while excluding moisture and air. The aim of the project was therefore to develop a method of depositing aluminum which could also be used technically, in other words, in open systems. Here two problems had to be solved: how can the moisture in the air gaining access to the electrolyte be kept low and how can moisture be ‘snatched away’ from the electrolyte. The central aspects were the use of a special dried gas which, being heavier than air, lay over the electrolyte like a buffer and thus acted as a moisture barrier. In addition, special zeolites were used: as so-called molecular sieves they could trap the water molecules in the electrolyte and thus keep the moisture level extremely low even for an extended period of time. This new method was implemented in a pilot installation for coating strip steel.

Outlook
Even though the results of the first technical trials on replacing cadmium are very positive, there still remains much to do. Primarily, electrolyte costs need to be reduced further since water-based systems are currently considerably cheaper. In addition, further improvements are required in the service life of the electrolyte and in its recyclability. Electro-deposited aluminum does have the potential to replace cadmium coatings in critical areas. One of the next steps will be to clarify various safety aspects.


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In its “Tools” division the Fraunhofer IST concentrates on the following areas among others:

- Plasma diffusion treatment and coating of press hardening and forging tools
- Tool coatings for aluminum, magnesium and titanium processing
- Nano-structured and high-temperature resistant coatings for cutting tools
- Antiadhesive tool coatings for the molding of plastics
- Diamond abrasive coatings for precision grinding tools
- Thin film sensors for tool monitoring

Important customers of this business division include coating service companies, tool manufacturers and users from, for example, the mold-making or automotive industries.

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COATING MECHANICALLY SMOOTHED TOOLS

In order to shorten the manufacturing chain of forming tools, surfaces are more and more frequently being hardened by mechanical smoothing operations such as deep rolling or hammer peening. Tool surfaces created in this way can be coated successfully without impairing the adhesive strength of the coatings. With some materials the adhesive strength of the coatings can even be improved.

In most cases forming tools used with sheet steel or aluminum are wholly or partially polished so as to ensure that the formed parts have a high surface quality. At the same time, efforts are made to obtain the longest possible service lives so as to avoid the need for repairs and to save preproduction and production costs. Wear-resistant tool coatings are developed with these aims in mind and make a considerable contribution to raising the tools’ productivity and to qualifying new and more attractively priced tool materials. Deep rolling and hammer peening are two methods which are available for mechanical smoothing which make finishing and polishing operations unnecessary. Surfaces created in this way have a mechanical hardening but this is coupled with a change in their topography. As part of the ZUTECH project “Mechanical surface smoothing for efficient tool- and mold-making” funded by the German Federation of Industrial Research Associations (AIF) the following questions are being investigated at the Fraunhofer IST:

- Is the coatability of tool materials with tried and tested wear-protection coatings assured?
- Are mechanically smoothed and coated tools just as wear-resistant as polished and coated reference tools?

The coatings then underwent a number of different adhesion tests in order to ascertain the resistance of the systems to delamination under static and dynamic loading. In the next step, to test the coatings under practical conditions, sheet aluminum and steel (galvanized/not galvanized) was deformed in the strip drawing test. Some very promising tool/coating combinations identified during a preceding screening were used here.

Results

In the mechanically smoothed state all of the material/coating combinations investigated were just as resistant to delamination as reference samples polished manually. The cast materials in the smoothed state actually tended to have improved coatability. This was confirmed by the strip drawing test. Wear, spalling and adhesions of the sheet materials were just as little in evidence on mechanically smoothed tools as on the manually polished reference tools used for comparison. The amorphous hydrocarbon coating (a-C:H or DLC) in particular showed outstanding effectiveness against aluminum accretions (pick-up). It has therefore been possible to demonstrate that coatings can deploy their outstanding properties even on material surfaces which are processed using the new methods we have described. In the future the question will have to be answered as to whether a combination with the hardening methods established in forming technology will yield even better results. 
FRICION INVESTIGATIONS AT TEMPERATURES UP TO 1000 °C

The friction and wear behavior of coatings and materials at high temperatures is becoming increasingly important especially as tools and even engine components are exposed to ever higher temperatures and loads which bring conventional materials up against their practical limits. A high-temperature tribometer is available at the Fraunhofer IST with which friction and wear tests can be carried out in air and also in an argon atmosphere at temperatures up to 1000 °C.

Friction investigations with the high-temperature tribometer

The pin-and-disk or ball-and-disk tests for investigating the tribological behavior of frictional pairs have been known for a long time now. However, difficulties are encountered in investigations at high temperatures and loads, such as are found with, for example, cutting tools or forging dies. Furthermore it is in most cases not possible to selectively adjust the ambient atmosphere (air or inert gas), which can have a decisive influence on friction and wear behavior. These difficulties have been overcome with the Fraunhofer IST’s high-temperature tribometer. Tests can be carried out under the following conditions:

- Normal force: 0.5–500 N
- Test piece temperature: RT bis 1000 °C
- Frictional velocity: 0–4 m/s
- Atmosphere: air, argon, nitrogen

In addition to the display of friction coefficient curves, the frictional partners are investigated using optical and electron microscope procedures. The friction tracks produced are measured by means of profile methods. EDX analyses deliver information about oxidation and diffusion processes which may occur.

Examples of investigations carried out

Taking TiAlN, TiAlCrSiN and c-BN coatings as examples, the influence of temperature and of an inert gas atmosphere in frictional contact with the ball-bearing steel 100Cr6 (1.3505) and stainless steel 1.4301 was investigated. The temperature of the coated disks varied from the room temperature range up to 930 °C with normal force and frictional velocity being kept constant. The tests were conducted in air and in the argon atmosphere in order to examine the influence of oxidation.

Results

When compared with tests at room temperature, the coefficients of friction above 530 °C decreased considerably. The influence of the inert gas atmosphere was very evident. Without the inert gas atmosphere the coefficient of friction was markedly lower with some coatings and this pointed to a friction-reducing effect of the oxide layers which formed. Indeed it was possible to significantly reduce adherences by means of the inert gas atmosphere as also by the use of a c-BN coating. It is noticeable that the degree of the adherences is not proportional to the value of the coefficient of friction. At this point further research work is needed.

Summary

The high-temperature tribometer available at the Fraunhofer IST represents a powerful, model-testing method for investigating friction and wear processes at high temperatures.

<table>
<thead>
<tr>
<th>Coating</th>
<th>Coefficient of friction in air</th>
<th>Coefficient of friction in argon</th>
</tr>
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<tbody>
<tr>
<td>Uncoated</td>
<td>0.6</td>
<td>0.4</td>
</tr>
<tr>
<td>TiAlN</td>
<td>0.5</td>
<td>0.3</td>
</tr>
<tr>
<td>TiAlCrSiN</td>
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<tr>
<td>c-BN</td>
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<td>0.1</td>
</tr>
</tbody>
</table>

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Silicon carbide on hard metals
Before being coated with diamond, carbide tools (WC-Co) are today pretreated by etching to remove the cobalt binder from the boundary layer since without this pretreatment it would not be possible to obtain adequate adhesion of the diamond coating. This type of pretreatment is very time-consuming and expensive and causes weakening of the boundary layer of the hard metal. By using SiC intermediate layers as a barrier against the diffusion of the cobalt binder in the hard metal the chemical etching of the cobalt before HFCVD diamond coating can be simplified.

Silicon carbide with different process gases
Silicon carbide (SiC) is a ceramic material of great hardness and offering a high resistance to oxidation. It is also used for applications in the semiconductor industry. At the Fraunhofer IST thin silicon carbide films can be deposited by HFCVD (hot-filament chemical vapor deposition) from different process gases: not only with tetramethylsilane (TMS) but also with a mixture of silane (SiH₄) and methane (CH₄); a cubic β-SiC is obtained which has a similar crystalline structure to diamond. The advantage of the silane/methane variant is that it is possible to set the proportions of the elements silicon and carbon independently of each other by metered dispensing of the gases. Due to differences in process control the substrate temperature in the case of coatings with TMS is about 100 °C higher.

Outlook
Work is currently in progress on depositing intermediate layer and diamond in a single process (in situ). Saving individual process steps between SiC deposition and diamond deposition means that coating times and costs can be reduced further. Furthermore, efforts are being made to lower the substrate temperature during diamond coating in order to increase the stability of the intermediate layer system.
In the "Energy, glass, façade" business field the work of the institute concentrates among other things on the development of:

- Inexpensive transparent conductive coating systems (TCOs) for photovoltaics and solar thermal panels, architectural and automotive glass
- Semiconductors coatings for thin-film photovoltaics
- Analytical methods for the characterization of thin-film solar cells
- Improved functional layers and coating processes on architectural glass
- Coating systems for fuel cells
- Improved inexpensive high-temperature corrosion protection for turbine blades
- Stable anodes and cathodes in lithium-ion batteries

Clients include companies in the glass, photovoltaics, automotive and electrical industries, the energy and construction sectors, manufacturers of heating and sanitary equipment as well as plant manufacturers and coating contractors.

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THERMAL INSULATION COATINGS FOR SAFETY GLASS

In virtually every case double-glazed insulating windows are coated on the inside with thin, transparent, silver-based coating systems in order to reduce the heat losses due to radiation. Special safety requirements apply when the glass is fitted in glass domes or on exterior façades. For the glass to break as it should, it must be prestressed. This is done by deliberately inputting stresses into the pane by means of heat treatment. For reasons of cost it is preferable to apply the coating even before the heat treatment. Prestressable low-emissivity coating systems for safety glass are under development at the Fraunhofer IST.

Low-emissivity coating systems in insulation-glass windows reduce the cooling down of the rooms behind them: due to their low emissivity, transparent silver layers reduce heat loss through radiation. The double-silver variant also reflects part of the infrared thermal radiation from the sun which is invisible to humans. Consequently there is less heating up in the interior in summer – particularly in the case of large glass façades. Safety glass is mandatory with overhead glazing. Brief heat treatment at around 650 °C ensures that the glass will break safely. The challenge: to save costs, the coating system must come through the process of thermal prestressing with its optical properties changed as little as possible.

Requirements made of the coating system

Fig. 1 shows the typical structure of a prestressable coating system with a layer of silver. The silver must be embedded in a transparent coating system so as to minimize by interference the high reflectivity of the silver. In order to achieve the prestressability desired, the following challenges were successfully tackled at the Fraunhofer IST:

- Prevention of increases in volume due to phase transitions, such as, for example, from amorphous to crystalline, in order to prevent spalling
- Development of a special base coating which blocks the unwanted diffusion of sodium from the glass
- Development of a top coating system for high mechanical durability and as oxidation protection
- Optimization of the adhesive strength of the silver layer

As for the lower adhesion layer, which provides a good connection between the silver layer and the base layer, a material was used which has been long established in the industry. To secure upward adhesion, a thin, transparent blocker layer was applied. Because they can oxidize, conventional metal blockers in this position often cause a marked and undesirable rise in transmission. Development work on the blocker included not only an investigation into different kinds of plasma excitation in the sputtering process for depositing the blocker but also the development of suitable blocker materials. In both cases the aim is to prevent an unwanted increase in volume. In the base layer and in the top coating system the barrier properties of various materials were tested. The basis for quantitative assessment here were these quality criteria:

- Sheet resistance $R_{sh}$ ($R_{sh}$ after treatment $=$ $R_{sh}$ before treatment)
- Optical transmission ($T_{vis}^{(pre)}$ $-$ $T_{vis}^{(post)}$ $=$ minimal)
- Mechanical durability in a brush washing machine.

Outlook

The next step will be to secure prestressability in the double silver coating system as well. Characteristics for assessing prestressability: optical transmission ($T_{vis}$), light scatter (haze), sheet resistance ($R_{sh}$).

Characteristics for assessing prestressability: optical transmission ($T_{vis}$), light scatter (haze), sheet resistance ($R_{sh}$).
HIGH-REFRACTIVE-INDEX TITANIUM DIOXIDE COATINGS

High-refractive-index titanium dioxide (TiO₂) is used for highly transparent low-emissivity coating systems with silver layers. Areas of application include architectural glazing. Until now TiO₂ with a refractive index of n = 2.4 has been used in industrial deposition processes. A higher refractive index could give greater transparency to the low-emissivity coating system. For this reason coating methods are being developed at the Fraunhofer IST which enable prestressable titanium dioxide to be produced by HIPIMS as a thin film with a higher refractive index.

State of development

HIPIMS is a variation of pulsed magnetron sputtering which permits plasma density or ion density to be boosted considerably during coating. This is exploited to optimize the material properties of thin films. What is disadvantageous in this technology is that in most cases the coating rate is low. The aim of development work at the Fraunhofer IST was to compensate for this disadvantage. By using a process control system, the reactive HIPIMS process can be run in so-called transition mode, which gives a higher coating rate. The measurement and control hardware used is robust and stable in the long term. In addition, a combined pulse pattern is used, as can be seen in Fig. 4. With this HPMF pulse pattern the high rate of an MF process is combined with the high plasma density of an HIPIMS process. The two approaches – control and combining the pulse patterns - together make possible a considerable increase in coating rates.

With a planar dual magnetron with PK500 cathodes it was thus possible to deposit TiO₂ coatings with a refractive index of n = 2.6. The dynamic coating rate here was 4 nm³/m² min with a power density of 14 W/cm². In addition to this rate increase, the prestressability mentioned is of interest as regards an industrial application in low-emissivity coating systems. The importance of prestressability can be seen from the micrographs of three different TiO₂ coatings shown in Figs. 1 to 3. These coatings had previously been subjected to a defined heat treatment at 700 °C. Fig. 1 shows a coating with a refractive index of n = 2.6 in which marked cracking (dark lines) is evident. By varying the HPMF process conditions this cracking tendency can be considerably reduced, as can be seen in Fig. 2. A concluding optimization step delivers the desired result, a crackfree, high-refracting TiO₂ coating which is prestressable (Fig. 3).

Outlook

Future activity at the Fraunhofer IST in this area will focus on improving cost effectiveness. To do so the process will be transferred to cylindrical cathodes to secure further rate increases. In addition, using an existing lateral control system should demonstrate that homogeneous coating properties are possible in the substrates with the reactive HPMF process even when relatively large cathodes are used.

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1 – 2 Cracking in titanium dioxide coatings following defined heat treatment.

3 Crackfree prestressable coating with a refractive index of n = 2.6

4 Schematic showing how pulse patterns are combined. The new HPMF pattern is obtained from a HIPIMS and an MF pattern. The result also combines the advantages of the two individual starting processes.
Polycarbonate glazing is very impact-resistant, lightweight and shapeable in a variety of ways. These advantages have an important role to play, especially in the automotive sector. On the other hand, polycarbonate, when exposed to the outdoor environment, does have a tendency to degrade and to become yellow. Coatings have been developed at the Fraunhofer IST which protects polycarbonate (PC) from abrasive, erosive and atmospheric environmental influences.

**Background**
Polycarbonate glazings are very sensitive and scratch easily under mechanical stress, such as rapidly occurs, for example, with windscreen wipers. In addition, environmental influences, such as ultraviolet radiation, cause a degradation of the surface. With the aim of eliminating this susceptibility which reduces the range of possible applications, the Fraunhofer IST, within the MINERVA research association, is researching into transparent, scratch-resistant coatings on polycarbonate which can be produced by plasma technologies.

**Implementation**
Various coating layers with different properties were applied to the polycarbonate using different methods. To improve scratch resistance a glasslike protective coating was developed. The coating is applied by a plasma-enhanced CVD method and by using tetramethylsilane (TMS) as a precursor. Currently the improved coatings have a stable coating adhesion (Fig. 3), high elasticity and meet the requirements of the Taber abrasion test for automotive glazing. Furthermore, to improve the performance of the polycarbonate, an ultraviolet protective coating was deposited between the substrate and the scratch-resistant layer by means of a PVD-PACVD hybrid process excited by intensive hollow-cathode glow discharge (see graph opposite).

**Outlook**
Optimization and a precise knowledge of the deposition parameters as well as the use of statistical DoE (design of experiment) with regard to the process parameters will bring about continuous improvements in not only the production process but also coating quality. The aim of research work at the Fraunhofer IST is to develop multilayer coating systems which meet the testing requirements of the automotive sector and in addition to be able to predict the effectiveness of the graded coating designs by means of numerical modeling.
CORROSION PROTECTION FOR BIPOLAR PLATES OF REDOX FLOW BATTERIES

Redox flow batteries are a proven technology for energy storage. The principle of the redox flow battery is that the energy is stored in two fluid electrolytes containing metal ions which can then be converted into electrical energy when they flow through porous graphite electrodes which are separated by a membrane. In order to make this technology more affordable and compact, new approaches are being investigated at the Fraunhofer IST.

The goal of this project is to develop a coating for metallic bipolar plates that can be used in redox flow battery (RFB) applications. Current systems utilize bipolar plates manufactured from graphite which in addition to the membrane account for a large portion of the cost for a cell. Although graphite is an ideal material to use because of its corrosion resistance and electrical conductivity, its poor mechanical strength requires a large bulky bipolar plate. To reduce the cost and volume of the RFB an alternative material must be investigated and researched for RFB applications. An ideal solution would be a metal-based bipolar plate, and in recent years this has been the focus of testing and research. Its inherent mechanical stability and electrical conductivity are ideal for RFB applications however its corrosion resistance is a problem. To counteract this, a coating could be applied to the metallic bipolar plate to protect it from the corrosive RFB environment.

A boron-doped diamond coating has been shown to be just such a coating with its good electrical conductivity and corrosion resistance against acids. However boron-doped diamond coatings are expensive and not applicable in the required dimensions. A solution to this boron-doped diamond problem is a metal-containing diamond-like carbon coating (a-C:H:Me) which is deposited by physical vapor deposition.

Experimental Procedure
Different a-C:H:Me coatings were applied to metallic substrates (stainless steel, titanium and aluminium alloys). The a-C:H:Me coatings selected to replace the current method were doped with chrome, vanadium, titanium and tungsten. To find the optimum solution, the coating thickness was varied in addition to the metal-containing percentage. The coatings were then analyzed for corrosion resistance, coating adhesion and mechanical stability. To ensure that the coating on the substrates functions properly, various tests have been carried out by both Fraunhofer IST in Braunschweig and Fraunhofer ICT in Wolfsburg. Test samples were prepared and the coatings were measured for the required thickness and metal-containing percentage, in addition to adhesion and mechanical stability. Also, electrochemical tests were carried out to ascertain if the coating and substrate material are suitable in the potential window required under the cyclical loads inherent with a RFB.

Test results
Initial testing shows that supplementing an a-C:H:Me coating for the currently used graphite filled polymer blends is possible. Under potentiodynamic and cyclic testing the a-C:H:Me coating is comparable with the existing graphite bipolar plates. A difference between coating thickness and metal percentage is apparent. Mechanical stability, good electrical conductivity in addition to the necessary corrosion resistance shows that a-C:H:Me coated bipolar plates can be an integral part in improving an RFB.

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Topics in the business field of "Optics, information, communication" include:

- The development of electrical contact and insulating coatings
- The development of coating systems for displays
- The development and design of multilayer coatings for optical filters
- The development of sensorized coatings
- The development of new materials and of structuring and metallization technologies as substitutes for ITO coating systems in flat-panel displays.

Clients of this business field include companies in the optical industry, in telecommunications, the automotive industry, manufacturers of displays and data storage media as well as plant manufacturers and coating contractors.

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INDUSTRIAL SHORT-CYCLE SYSTEM FOR THIN-FILM SENSOR SYSTEMS

Thin-film strain gauges which are coated directly onto the workpiece surface offer a number of different advantages, such as, for example, miniaturization and high positioning accuracy. In addition, special piezoresistive materials are highly sensitive to strain, which above all means a better signal-noise ratio at low levels of strain. Producing these highly sensitive coatings on an industrial scale calls for a very high standard of efficiency. At the Fraunhofer IST the production process has been successfully transferred to an industrial short-cycle high-rate sputtering system with throughput rates twenty times higher. Coatings based on diamond-like-carbon (DLC) are used for the sensor material.

Compensation for the temperature coefficient of electrical resistance
Since pure DLC has a negative temperature coefficient of resistance (TCR), adding a metal with a positive TCR can provide temperature compensation. One metal preferred for this purpose is nickel. The TCR is negative with a low nickel content and positive with a high one. The passage through zero occurs at approx. 55 atom % nickel, irrespective of whether coating was static or dynamic. Nor has the type of coating installation any influence on the nickel value. This is also confirmed by the results of earlier studies which show that the TCR, in a first approximation, depends solely on the nickel content of the coating and is very substantially independent of other process parameters such as operating pressure and substrate bias voltage.

Realization of a high strain sensitivity
The k factor, which is a measure of strain sensitivity, is on average slightly lower with dynamic deposition than with static deposition using the same coating equipment (a Balzers BAS 450). The maximum values of approx. 10 are however comparable for both series. With a high-rate sputtering system (an Impact Coatings IC300) the maximum k factor of approx. 15 is considerably higher than is the case with coatings produced in the box coater. In all cases the maximum k factor occurs at approx. 55 atom % nickel and thus approximately at the passage through zero of the TCR.

Increasing efficiency by using a high-rate short-cycle system
More important than a further increase in the k factor is creating a process for Ni-DLC coatings as strain sensors which can be implemented on the industrial scale. Comparable maximum k factors of around 10 have been achieved for nickel DLC with static and dynamic coating; with static coating in the high-rate sputtering system it was possible to increase strain sensitivity a further 50 % with k factors up to approx. 15. The bar diagram below shows clearly that all process steps take much longer in the box coater. The greatest difference, if we disregard evacuation time, is in the process times for the actual deposition of the sensor coating.

Comparison of process times required by the two coating installations used.
SMART MATERIALS: PIEZOELECTRIC COATINGS FOR MICROSYSTEMS

Microelectromechanical systems or MEMS are microelectronic components which also have mechanical functions, such as, for example, the acceleration sensor for triggering airbags. Electromechanical converter sensors and actuators are an important component of MEMS. In most cases MEMS are manufactured using coating techniques, often on the basis of known silicon semiconductor technologies. For this reason even the mechanical sensors and actuators should be made as coatings and integrated directly into the production process. At the Fraunhofer IST piezoelectric PZT coatings are produced by gas flow sputtering (GFS) with individualized adjustment to the application in question.

Lead zirconate titanate or PZT

PZT is a mixed oxide of lead (Pb), zirconium (Zr) and titanium (Ti), a ceramic material which has far and away the best piezoelectric properties and which is thus outstandingly suitable for electromechanical sensors and actuators. Piezoelectricity is the term given to the property of solid bodies to create an electric charge under applied elastic deformation and vice versa. However, the production of usable PZT coatings is a difficult process. In the first place it is necessary to set the composition of the coatings with extreme precision. Secondly, a very specific crystalline structure must be achieved: the perovskite structure.

Gas flow sputtering

PZT coatings produced by magnetron sputtering are only a few micrometers thick and are, for example, suitable for use as sensors. Actuators, on the other hand, need a considerably greater thickness of coating, between 5 and 25 µm. Magnetron coatings this thick would soon flake off. With the gas flow sputtering process developed at the Fraunhofer IST, thick and stable PZT coatings can be produced which have very good piezoelectric properties.

200 mm wafers

MEMS are being developed in close collaboration between the Fraunhofer ISIT in Itzehoe and the Fraunhofer IST. Overall production development, including the piezo electrodes and their structuring, is the responsibility of the Fraunhofer ISIT while the Fraunhofer IST handles the development of the key PZT coating. At the Fraunhofer IST the entire technology has now been switched over to 200 mm silicon wafers (previously 150 mm). Therefore the gas flow sputtering process at the Fraunhofer IST also had to be transferred to this wafer size which was successfully carried out in 2012. The greatest challenge was the development of a corresponding substrate heater for keeping the wafers at a steady and homogeneously distributed temperature of approx. 600 °C during coating.

Coating properties

The composition of the PZT coatings is very precisely set to PbZr0.5Ti0.5O3. The crystalline structure (of the columns) is that of a perovskite, with a marked (101) and (110) texture (see top diagram). The piezo constant d33 of a coating 2.7 µm thick (deflection in direction of polarization, measured at the Fraunhofer IST) is around 150 pm/V (see lower graph). The maximum deflection in this measurement was more than 12 nm. Good magnetron coatings have in comparison a d33 coefficient of 100 pm/V. The coating rate is 1.5 nm per second.

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**BONDING: JOINING WITHOUT ADHESIVE**

New materials and material composites are one of the prime foundations of innovation. Special progress has been made at the Fraunhofer IST in bonding different materials. Bonding combines the advantages of gluing and welding but without the need for adhesive or for melting the surfaces.

**Surface functionalization replaces adhesive and lowers the joining temperature**

One important precondition for the planar joining of materials is the formation of chemical bonds between the surfaces which will have long-term stability. To do so, chemically reactive groups are ideally generated on the surfaces which react with each other under the influence of moderate temperatures. These reactions create permanently solid bonds between the surfaces to be joined together. Surfaces as smooth as possible are to be preferred since they offer a large effective contact surface on the atomic scale. The number of chemically reactive groups on the surface can be very efficiently and inexpensively increased with atmospheric-pressure plasmas. This functionalization of surfaces by chemical gas-phase reactions is at the same time particularly gentle. For this reason atmospheric-pressure plasma processes are, as experience at the Fraunhofer IST shows, outstandingly suitable for the establishment of entirely new joining methods for use in industry.

**Bonding glass and silicon**

In microsystem technology, multiple layer structures are created by the planar joining of glass and silicon wafers. Various joining methods are employed here, such as anodic, eutectic or adhesive bonding as well as direct, glass-frit or thermocompression bonding. The advantage of direct bonding is that no intermediate layers are required. However, in the case of silicon wafers without adequate surface pretreatment the temperatures necessary for delivering high strength lie between 800 °C and 1100 °C. By means of an atmospheric-pressure plasma pretreatment the density of the chemically reactive groups is increased and the required temperature can fall as low as 100 °C. A new method has been developed at the Fraunhofer IST by which the increase in bond strength can be determined in situ during conditioning. In this way pretreatment processes can be optimized to make them much simpler.

**Joining plastic to plastic and plastic to metal**

Adhesive-free joining methods used in industry include various types of lamination. However, with these methods the material properties of the bonding partners frequently suffer, such as, for example, optical or tactile quality. In addition the bonding partners are often not mutually compatible. At the Fraunhofer IST success has been achieved in functionalizing the surfaces of the substrates by means of atmospheric-pressure plasmas in such a way that they react chemically, making fixed bonds even at low temperatures. The functionalization required can be effected not only by an oxygen-free activation of the surfaces but also by depositing coatings with functional groups.

**Outlook**

As part of current work at the Fraunhofer IST the results obtained so far have been transferred to other materials, such as, for example, bonding fiber-reinforced composites and sheet metal for lightweight design applications.

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At the center of activities in our ‘Life Science and Ecology’ business sector is the development of surfaces for applications in medical technology, biotechnology and environmental technology. Examples include:

- Selective functionalization and coating of surfaces by means of atmospheric-pressure plasma processes (for example, for bioanalytics, medical technology or migration barriers)
- Diamond-coated electrodes for the electrochemical disinfection of water and for treating wastewater
- Metallization of plastic surfaces for biosensors
- Internal coating of microfluidics components, cell culture bags and tubing
- Biocompatible antifriction coatings (for example, diamond-like carbon coatings) for applications in medical technology, such as in prosthetics
- Plasma treatment for the restoration and conservation of cultural assets

Customers of this business division include companies from the pharmaceutical industry, biotechnology, medical technology, the foodstuffs industry, the chemical industry and environmental engineering.

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BIOFUNCTIONAL SURFACES

The interactions at the boundary surface between a surface and a medium play a crucial rôle in biological applications. Many inexpensive materials cannot offer an attractive surface for interacting with biomolecules. At the Fraunhofer IST surfaces of the most varied materials and geometries are being functionalized or coated using atmospheric-pressure plasma processes. This "dry" method is primarily characterized by short process times, the absence of solvents or vacuum equipment and also a high degree of flexibility.

Creating biofunctional surfaces by the atmospheric-pressure plasma process

Dielectric barrier discharge (DBD) at atmospheric pressure offers a wide range of possibilities for modifying inert surfaces so that they can be used for biomedical applications. Depending on requirements, surface properties can be set by different methods including:
- Activation to improve wettability with polar media
- Functionalization to create chemically reactive groups on the surface, or
- Deposition of functional coatings.

In comparison with other surface modification methods, atmospheric-pressure plasma processes have the advantages of not using solvents and of needing only comparatively short process times to carry out suitable modification of the substrate.

Not only flat substrates but also substrates with complex geometries can be modified. These, for example, include PCR tubes, microfluidic systems, bags or scaffolds. The following substrate materials can be processed:
- Polymer foils
- Glass
- Silicon wafers
- Metals
- Porous materials
- Textiles
- Leather

Identification of functional groups

Not only the coating function is crucial for the subsequent application but also the type and reactivity of the functional groups. The chemically reactive groups should directly interact with the biomolecules or be an initiation site for further wet-chemical process steps in which the substrates are equipped with a secondary modification. The functional groups cannot always be identified directly, which means that specific detection reactions need to be developed. Detection is then effected by means of fluorescence tests, FTIR spectroscopy, XPS or REM/EDX.

Application examples

An in-air corona treatment of microtiter plates or cell culture flasks to improve the wettability of the surface is already in widespread use in industry. In contrast, functionalization under defined atmospheres using atmospheric-pressure plasma processes is suitable to generate nitrogen containing groups, like primary and secondary amines, on the surface. Such modifications make it possible to cultivate adherent cell lines on the substrate.

Another example is the internal coating of closed plastic bags in which human stem cells can grow adherently in a GMP-conforming environment. With local surface treatments the location-selective growth of adherent cell lines becomes possible. Furthermore, microfluidic systems can be modified so that mixtures of substances can be compartmentalized and subsequently separated.

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1 Amination of a 24-well polystyrene microtiter plate by the atmospheric-pressure plasma process.
2 HeLa cells in an amino-functionalized polystyrene microtiter plate.
3 Control of cell adhesion on a PBT-PEOT scaffold by coating via atmospheric-pressure plasma process.
4 MC3T3 cells after viral infection on day 12 of cultivation on a plasma-treated PBT-PEOT scaffold.
In medical technology biosensors are used in the point-of-care environment, such as in fast testing to determine glucose or lactate levels in the blood. Disposable diagnostics are becoming increasingly popular. For their amperometric-enzymatic measurement principle thin metal coatings of gold, platinum or palladium are used. In the “Plasma printing and packaging technology – P³T (FKZ 02PO2444)” BMBF project an innovative resource-friendly process has been developed for the wet-chemical location-selective deposition of palladium coatings on polymer film reel-to-reel.

Plasma printing: location-selective surface activation
The first process step in P³T is location-selective plasma activation by means of microplasmas at atmospheric pressure. To do so a reel-to-reel line was set up at the Fraunhofer IST in which plastic film can be continuously activated at speeds up to 5 m/min and with structural resolutions up to 50 μm. One of the core components here is an engraved metal press roller of the type familiar from conventional gravure printing. With a suitable arrangement using a high-voltage electrode, microplasmas can be generated on the basis of dielectric barrier discharges as the film passes over the engraved recesses in the roller. Since the roller rotates together with the film, the engraved pattern on the roller, in other words the basic sensor structure, for example, is transferred by the microplasmas to the film surface as a location-selective chemical functionalization (Fig. 1).

Wet-chemical metallization
In the P³T project the plasma printing process is carried out with a nonflammable process gas consisting of nitrogen with an addition of 3.4 % hydrogen so that the location-selective functionalization on the film surface includes some groups containing nitrogen. The surfaces thus functionalized are then passed through the appropriate baths to wet-chemically deposit a thin palladium coating. The metallization procedure has the following individual process steps:
- Palladium chloride and hypophosphite solution for seeding
- Starting metallization with chemical nickel (thickness: 25 ± 5 nm)
- Metallization with chemical palladium (thickness: 100 ± 10 nm)

Sensor cards have been produced in this way with 80 sensor structures in each case. A very good, homogeneous metallization over an area of 160 x 160 mm² was achieved under laboratory conditions using chemical nickel as the starting metallization (Fig. 2).

Functional testing of the biosensors
At the project partners SensLab - Gesellschaft zur Entwicklung und Herstellung bioelektrochemischer Sensoren mbH, ten cards with a total of eight hundred sensors were further processed to produce lactate sensors. The functioning of four hundred of these sensors was inspected statistically. The results:
- In the forty sensors tested on a card the statistical error was 3.5 %
- For all 400 sensors the statistical error was 4.5 %

The results help to confirm that fabricating these sensors by plasma printing is very suitable for the production of biosensors. The quality of the sensors on a card is high and reproducibility between the individual batches is acceptable.

Outlook
Thanks to the development work in the P³T project, it will be possible in future to produce base structures for biosensors in low production quantities at the Fraunhofer IST. Work is currently seeking to improve the quality of the sensors and to reduce reject rates. In this regard investigations are looking into whether X-ray fluorescence analysis is basically suitable for use in quality assurance within a production process. In collaboration with the project partners work is also in progress regarding the transfer to industry of the prototypes which have been developed.
In pursuing the business areas that were showcased in the previous chapters the Fraunhofer IST utilizes a wide spectrum of competencies in the fields of special coating systems on the one hand, and coating processes on the other hand:

**Low pressure processes**
- Magnetron sputtering and HIPIMS
- Hollow cathode processes
- PACVD- and hot-filament CVD processes
- Hot-wire-CVD-processes
- Atomic layer deposition (ALD)
- Modeling of low-pressure processes
- Plasma diffusion process

**Atmospheric pressure processes**
- Multi component systems for electroplating
- Non-aqueous electroplating
- Atmospheric pressure plasma processes
- Micro plasma
- Low temperature bonding
- Plasma metalization
- Corrosion protection

**Micro and nano technology**
- Functionalizing of interfacial layers
- Micro and sensor technology
- Thin films
- Nano composite coatings

**Electrical and optical coatings**
- Optical coatings
- Transparent conductive coatings
- Diamond electrodes
- Silicon-based coatings for photovoltaics and microelectronics
- Oxide semiconductors
- Insulation coatings
- Piezoelectric coatings

**Super hard coatings**
- Diamond
- Cubic boron nitride (cBN)

**Friction reduction and wear protection**
- Amorphous carbon coatings (DLC)
- Hard coatings
- Plasma diffusion
- Dry lubricant coatings
- Erosion protection coatings
- Corrosion protection coatings

**Analytics and quality assurance**

In addition the institute offers a broad spectrum of cross-sectional services: Surface pre-treatment, thin film development, process technology (including process diagnostics, modeling and control), surface analysis and thin film characterization, training, application-oriented film design and modeling, system design and technology transfer.
COATING AND SURFACE ANALYSIS FOR INDUSTRY

Coatings and surface modifications are becoming increasingly important in the industry. State-of-the-art coating analysis is essential for developing an understanding of coatings and for making efficient use of them. For more than 20 years, the Fraunhofer IST has been an experienced point of contact for services in the area of analytics. With more than a hundred external orders a year from a variety of industry fields (automotive, coating, optics, electronics, consumer, and others), the Fraunhofer IST can meet the requirements made by industrial clients (competent advisory service, promptness, confidentiality, price-performance ratio) and provides an optimum combination of analytic processes for individual demands.

What the Fraunhofer IST offers

The chemical composition of a coating is generally the most important parameter and heavily influences its application properties: hardness, friction, wear, optical, electrical, magnetic, and other properties are extremely dependent on the chemical composition of the material. We are able to determine the composition of coatings with a high lateral (1 µm) and the highest vertical (1–2 nm) resolution with a whole range of methods, e.g. with:
- SEM with EDX/WDX: 1 µm spatial resolution, ideal for failure analysis, coating composition and thickness measurement
- SIMS: depth profiles with 1–2 nm depth resolution for the characterization of multilayers, interfaces, trace elements, hydrogen content and adhesion problems
- XPS/ESCA: for analyzing thin (≤ 5 nm) surface layers (contaminations) and binding states
- GD-OES: fast method for depth profiles of thick films
- RFA/XRF: fast characterization in air

In addition, X-ray diffraction (XRD) makes it possible to analyze the crystalline structure of coatings and to determine grain sizes, textures, or internal stresses. Lastly, at the Fraunhofer IST a variety of microscopy methods is available: from an optical binocular loupe, to confocal laser microscopy, and scanning electron microscopy to atomic force scanning tunnel microscopy with a maximum resolution.

Testing technology

Along with field tests, testing technology makes it possible to verify the application properties of coatings with less effort and under reproducible conditions. This is important not only in the development of coatings, but also in quality control during production.

One core area of the Fraunhofer IST is the testing of mechanical-tribological coating properties, e.g. micro and nano hardness, coating adhesion, film thickness, wear, and friction under different loads, temperatures and media as well as corrosion resistance. Here, the Fraunhofer IST offers a variety of tests, also in accordance with DIN/ISO/ASTM standard. Another focus is on optical measurements of coating systems, such as reflection, transmission, absorption, refractive index, color index, scattering, and special processes for photovoltaics, photocatalytic activity, or particle density on surfaces. The Fraunhofer IST has a broad and profound expertise in both fields as the development of coatings has been carried out by the institute itself for decades.

WHAT THE FRAUNHOFER IST OFFERS

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HIGHLY IONIZED PLASMAS: DEVELOPMENT, TRAINING, CONSULTANCY

New innovative methods for creating improved or entirely new coating systems are a key to market leadership. The latest development in the field of physical vapor deposition which is currently finding its way into industry is high power impulse magnetron sputtering (HIPIMS or HPPMS).

Over the last decade the Fraunhofer IST has become the world’s leading institute in the application-and product-oriented development of HIPIMS technology. In heading a European network in the field of highly ionized pulsed plasma processes (COST Action MP0804 HIPP Processes) the Fraunhofer IST brings together the leading experts in HIPMS technology. The institute has at its disposal nearly all of the HIPMS pulse generators which are commercially available (AE, Hüttinger, Magnus, Melec, Z Pulzer) and tests and develops them in collaboration with the corresponding company. At the moment there are six industrial coating installations with planar and tubular cathodes up to 750 mm in length which are permanently equipped with HIPIMS technology. Optical emission spectroscopy, opposing-field analyzers and also Langmuir probes are available for plasma diagnostics.

Finer PVD coatings with HIPIMS

HIPIMS technology is an effective method to use when thin-film systems with a dense microstructure and/or a high ratio of coating hardness to the modulus of elasticity are to be deposited.

HIPIMS patent survey

A patent survey was prepared at the Fraunhofer IST with the aim of gathering together all of the important patent-related information on the subject of high power impulse magnetron sputtering. This survey offers a comprehensive overview of the international patent landscape. The advantages at a glance:

- The HIPIMS patent survey offers permanent up-to-dateness and can be used as a basis for decision-making regarding submission of one’s own developments, and as a dependable source of information for analysis of the competition and of trends.

The survey covers all internationally relevant industrial property rights, R&D facilities and companies owning more than a single industrial property right. The industrial property rights are subdivided by process patents and by application patents and with regard to their legal status. A countries listing shows the countries where there are legally valid patents. The patent activities of R&D facilities and companies can be read off from the ranking. The first pages of the survey include a brief description of each industrial property right. The entire patent survey can be purchased from www.ist.fraunhofer.de.

Our range of services

- Basic HIPIMS training (introduction to HIPMS technology as well as hands-on training with different pulse generators and operating modes)
- Customer-specific training courses and advisory services
- Coating and process development
- Component development (testing and evaluation of hardware)
- Market studies (for example, a current patent survey – presented in more detail below)

Number of patent families in the HIPIMS field for processes and equipment as well as coatings and applications.

| Processes and equipment | 25 |
| Coatings and applications | 11 |

filed  granted

METALLIZED TRENCH: 1 µm wide and deep.

HIPIMS DLC, nano-hardness ~ 40 GPa, plastic hardness ~ 60 GPa.

HIPIMS patent survey 2012.

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PHOTOCATALYTIC REMOVAL
OF NITROGEN OXIDE

More than 80 percent of currently used photocatalytic products find their application in the building sector and here mostly for outdoor applications. The minimization and reduction of environmentally hazardous and toxic substances which result from road traffic or combustion processes in industrial plants and power plants are typical application fields. A quantitative evaluation of the photocatalysts is carried out via a nitrogen oxide removal test, standardized according to ISO 22197-1. The test is now also available at the Fraunhofer IST.

Photocatalytic air purification
With photocatalytically active materials, which are activated by absorption of sufficient energetic light – mostly UV radiation – adsorbed organic air pollutants (e.g. volatile organic compounds: VOCs) are decomposed into water and carbon dioxide. Inorganic compounds, such as nitrogen oxides (NOx), are oxidized to the less harmful mineral salts (carbonates, nitrates, sulfates and so on). Photocatalysts are mainly used outdoors as functional products, such as roof tiles, concrete, facade plaster, or asphalt, in order to make the anthropogenic air pollutants decompose into harmless products.

Determination of photocatalytic efficiency
If materials contain the photocatalyst or have been functionalized via a thin film, their air-purifying effect can be determined with the nitrogen removal test according to ISO 22197-1. The substrate to be tested is UV-irradiated and continuously exposed to the pollutant nitrogen monoxide (NO), which is oxidized to nitrate due to the photocatalytic process. With the knowledge of ambient parameters, such as

- Wavelength,
- Irradiation intensity, or
- Gas concentration and ratios,
  
  the reaction rate of the removal of NO allows a quantitative evaluation of the photocatalytic efficiency.

Service
The modular reactor which is installed at the Fraunhofer IST makes a standardized characterization of samples possible for a variety of sizes and geometries. At the same time it allows the adjustment of the measurement conditions to actual requirements. In order to do so, defined adjustment of the following measuring parameters, among others, is necessary:

- Humidity
- Volume flows
- Flow conditions
- Pollutant concentration

Porous materials, textiles, or honeycomb catalysts can be measured by using a continuous flow reactor in combination with a standard setup for measuring planar 2D samples in a flat bed reactor. This method supplements the Fraunhofer IST’s repertoire of analytics in the field of photocatalysis with another standardized process for the characterization of photocatalytically active materials and thin films as well as for the determination of their performance in existing products. Additionally, it is planned to enhance the testing technology with VOC analysis in order to gain detailed information on intermediate and end products which form during the decomposition of organic compounds.

Typical measurement.
PLASMA SIMULATION AT THE FRAUNHOFER IST

A parallel simulation software program for gas discharges in computational domains of any degree of complexity has been developed at the Fraunhofer IST. The focus of the simulation was on gas discharges in the low-pressure or low-temperature ranges as particularly used in plasma coating processes. With the simulation software a powerful analysis and development tool has been created for the corresponding methods such as magnetron sputtering or plasma-chemical gas-phase deposition.

The particle-in-cell Monte Carlo (PIC-MC) method

To simulate the dynamics of plasmas in the spatial and velocity domains the so-called “particle-in-cell Monte Carlo” (PIC-MC) method has been implemented at the Fraunhofer IST. In the PIC-MC method the physics of neutral particles and charge carriers is represented in the simulation space by representative macro-particles. The spatial and velocity changes of all of the macro-particles as a function of wall and particle interactions are here calculated within discrete time steps. To filter statistical noise out of this representative depiction the particle states are averaged over several time steps and particles per cell. Macroscopic state variables such as current or temperature distributions can then be obtained from these averaged particle states. Starting with an initial distribution the simulation is ended once a steady state is reached or a corresponding termination criterion is satisfied.

Features of the PIC-MC simulation software

This simulation software from the Fraunhofer IST includes a comprehensive database with collisional cross-sections for different species of inert and reactive gas, metal atoms and certain more complex molecules. The PIC-MC simulation itself has been parallelized via the approach of domain decomposition so that the computing and memory load can be efficiently distributed over any number of networked computer systems. A finite-elements interface means that complex geometry models can be mapped onto the computational grid of the simulation space. The physical properties of surfaces and other simulation parameters can be defined via an automatically generated parameters file.

Our range of simulation services

- Optimization of vacuum coating processes and installations
- Licensing of the DSMC/PIC-MC simulation environment for low-pressure gas flows and gas discharges
- Advice and training

Outlook

For a number of years now PIC-MC software licenses have been sold even in countries outside Europe, including to companies from Japan and South Korea. This shows the software’s performance under international comparisons and acts as a stimulus to further developments. New modules for numerical field calculation are planned in order to be able to simulate inductively stimulated and high-frequency stimulated plasmas as well. The user interface is also to be considerably simplified by automating adjustment of the simulation parameters to boundary conditions.

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In 2012 the Fraunhofer IST once again appeared on various platforms. An overview of the most important events and activities of 2012 follows:

- Trade fairs and conferences
- New Fraunhofer IST Application Center for Plasma and Photonics
- Events, colloquia, workshops
TRADE FAIRS AND CONFERENCES

Hannover Messe 2012
Hannover, April 23–27, 2012. At this year’s Hannover Messe, the Fraunhofer IST was oriented by urgent future-related topics and social trends, such as the implementation of an alternative energy supply, alternatives for scarce materials and raw materials, or mobility in the 21st century. Various exhibits focusing on the subject of “Researching for a viable future” were presented, such as, for example, diamond electrodes which make clean drinking water possible even in remote areas without the use of chemical additives and an ultra-thin “all-rounder coating” which, among other things, can keep car windshields free of ice in winter - and without consuming active energy.

Optatec 2012
Frankfurt, May 22–25, 2012. At the joint Fraunhofer booth, the Fraunhofer IST showcased the highlights of current developments in the field of precision optics at the trade fair for optical technologies, components and systems in Frankfurt. Here, the department “Optical Functional Coatings” for the first time presented a state-of-the-art sputtering system for the manufacture of high-precision optical interference systems which was developed at the Fraunhofer IST.

Achema 2012
Frankfurt, June 18–22, 2012. The Fraunhofer IST presented the latest research results on the topics “Atmospheric Pressure Plasma Processes” and “Biofunctional Surfaces”. A broad range of topics was addressed with the exhibits that were presented at Achema 2012 – microfluidics, electrochemical bio sensors, blood bags, functionalized microtiter plates as well as internally coated catheters and hoses.

9th International Conference on Coatings on Glass and Plastics - ICCG9
Breda, The Netherlands, June 24–28, 2012. At the technical exhibition, which took place during the conference, the Fraunhofer IST presented results from research into the “ice-free window” and recent development work in the field of p-TCOs.

PSE 2012
Garmisch-Partenkirchen, September 24–28, 2012. The most recent developments related to the guiding theme “Plasma technologies for efficient energy conversion and storage” were presented during the largest plasma conference in Germany, the “13th International Conference on Plasma Surface Engineering – PSE 2012”.

EU PVSEC 2012
Frankfurt, September 24–28, 2012. In order to provide German solar cell manufacturers with the possibility for a head start in the international market again, especially in the price competition with Asian manufacturers, researchers of the Fraunhofer IST have developed coating processes and thin film systems aimed at lowering the production costs of solar cells drastically and presented the results at the EU PVSEC trade fair.

EUROBLECH 2012
Hannover, October 23–27, 2012. At a joint Fraunhofer booth during Euroblech 2012, the Fraunhofer IST presented its expertise in the coating of tools and the forming of titanium alloys which are of great interest e.g. in automotive and aerospace engineering, medical technology and for corrosion-resistant components. In addition, the Fraunhofer IST was represented at a second booth this year with the group “Micro and Sensor Technology” at the booth of the European Research Association for Sheet Metal Working EFB.

GLASSTEC 2012
Düsseldorf, October 23–26, 2012. Under the guiding theme “With glass and plastics into the future”, the joint Fraunhofer booth presented a broad range of competencies with and related to the material glass – from the development and coating of glass to photovoltaics and transparent electrodes. Important topics of the Fraunhofer IST were new ALD processes, a new sputtering module, and the “ice-free all-rounder coating”.

Hannover Messe 2012, 1 Prof. Dr. Günter Bräuer, director of the Fraunhofer IST, in conversation with Prof. Dr. Hans-Jörg Bullinger, President of the Fraunhofer-Gesellschaft, at Hannover Messe 2012.

Joint Fraunhofer booth at EU PVSEC 2012, 2.
In summer 2012, a new future-oriented research institution started its work in Göttingen, a site for innovations and the transfer of knowledge. Modern plasma technology gains a further foothold in the region of Niedersachsen with the Fraunhofer Application Center for Plasma and Photonics at the HAWK – University of Applied Sciences and Art. The center is headed by Prof. Dr. Wolfgang Viöl, vice president of the HAWK. For more than ten years he has been doing research on the effect of the ionized gas at Göttingen’s HAWK faculty of Natural Sciences and Technology and was instrumental in setting up the cooperation with the Fraunhofer IST in Braunschweig.

Customized plasma technologies for the industry and consumers

Thanks to a new funding concept it was possible for the first time to set up cooperative application centers of the Fraunhofer-Gesellschaft together with universities and universities of applied sciences. The Fraunhofer IST Application Center focuses on plasma technologies. In combination with other technologies, the ionized gas mixture – which occurs e.g. in flashes of lightning and is known as the fourth state of matter – provides a key to scientific and technical progress, innovative capacity for action, and technological know-how.

The center considers itself mainly as a point of contact and cooperation partner in all things related to future-oriented innovations. As small and medium-sized businesses often have only small R&D departments or even none at all, the aim is to provide them with a chance to advance and modernize their business according to their own wishes and plans. Large companies get to test ideas – without having to consider mass production immediately.

Diversity of competencies in surface modification

For the competencies the emphasis is especially on the following fields:

- Development of specific plasma sources: components, hand-held devices, equipment
- Plasma in the field of life sciences: plasma medicine (particularly dermatology), bio engineering, pest control
- Laser plasma hybrid technology for material processing
- Plasma surface modifications: renewable raw materials (wood, seeds, and so on), glass (optics, architectural glass), metals and silicates (wire products, foils, wafers) as well as plastics and fibers (plastic films, textiles, CFRP, GFRP)
- Plasma characterization: analytics and diagnostics
- Photonics: laser technology, sensor technology, laser diagnostics

Prof. apl. Prof. Dr. Wolfgang Viöl heads the new application center

Since 1994 Wolfgang Viöl has been teaching and doing research as a professor at the HAWK University of Applied Science and Art Hildesheim/Holzminden/Göttingen in Göttingen. In 2011 he was also appointed as an adjunct professor at the Clausthal University of Technology. After he earned his doctorate at the University of Düsseldorf in 1988, he qualified as a professor at the university’s Institute for Laser and Plasma Physics before he went on to set up a work group for laser and plasma technology at the HAWK – which, by now, has more than 50 team members. Along with a number of novel applications and innovations, the Fraunhofer Application Center for Plasma and Photonics, headed by Prof. Viöl, developed from this particular focus on laser and plasma technologies. Prof. Viöl is involved in strengthening and improving research at universities of applied sciences and the connection between them and the industry, e.g. as vice president for research and transfer at the HAWK and as the first professor of a university of applied science in the DFG review boards.
EVENTS, COLLOQUIA, WORKSHOPS

Literary-musical theme night for the 225th birthday anniversary of Joseph von Fraunhofer
On the occasion of the 225th birthday of Joseph von Fraunhofer on March 6, 2012, the Evangelische Akademie Abt Jerusalem in Braunschweig dedicated a literary-musical theme night to the famous patron of the Fraunhofer-Gesellschaft, held on July 9, 2012. The event was followed by a panel discussion during which Professor Bräuer, director of the Fraunhofer IST, answered questions regarding the concept and research aims of the Fraunhofer-Gesellschaft and the Fraunhofer IST.

Opening of the German-South African Year of Science in Cape Town
The South African Partner of the Fraunhofer IST at Tshwane University of Technology in Pretoria, Bob Bond, and the deputy director of the Fraunhofer IST, Prof. (TUT) Wolfgang Diehl, presented developments on the topics of “Hydrogen Bike Technology” and “Water treatment with diamond electrodes” as part of the opening ceremony for the Year of Science between Germany and South Africa. Naledi Pandor, minister of science and technology, and Federal Minister Annette Schavan also attended the event.

Fraunhofer IST starts research cooperation with Indian university IIT Indore
In the future, the Fraunhofer Institute for Surface Engineering and Thin Films IST and the Indian Institute of Technology IIT in Indore will closely collaborate in the field of coating and surface technology. Representatives of both institutes have signed a Memorandum of Understanding and have thus laid the foundation for joint research activities. Against the background of the rapid growth of India’s automotive industry, especially in automotive construction, the aim of the collaboration between Fraunhofer IST and IIT Indore is to find solutions for future challenges in the field of mobility.

Researchers of the Fraunhofer IST support Asahi Glass India
In this year, the close collaboration with Indian research partners has lead researchers of the Fraunhofer Institute for Surface Engineering and Thin Films IST to supporting the company Asahi Glass India in putting a new glass coating system into operation. They provided on-site employee training and assistance, suggested coating systems, produced prototypes and characterized the manufactured samples.

Dedication of the Fraunhofer IST Application Center
“Two Fraunhofer Institutes – Two Application Centers” was the slogan for the formal opening of the new application centers of Fraunhofer IST and WIKI in Braunschweig. The Minister of Science and Culture, Prof. Dr. Johanna Wanika, inaugurated the Fraunhofer Application Centers which are the first two of their kind nationwide. With customized plasma technology, the Fraunhofer IST Application Center for Plasma and Photonics APP in Göttingen aims at focusing on atmospheric pressure plasmas in production processes and surface technology. Representatives of both institutes have signed a Memorandum of Understanding and have thus laid the foundation for joint research activities. Against the background of the rapid growth of India’s automotive industry, especially in automotive construction, the aim of the collaboration between Fraunhofer IST and IIT Indore is to find solutions for future challenges in the field of mobility.

Festive colloquium for Dr. Klaus Bewilogua
The Fraunhofer IST’s success in the field of diamond-like carbon DLC has for more than 20 years been closely connected to the research achievement of Dr. Klaus Bewilogua, head of the department “New Tribological Coatings”. With a festive colloquium on November 29, 2012, the institute said farewell to one of the world’s leading experts on thin DLC and cubic boron nitride coatings. Thanks to his work in particular, the Fraunhofer IST was able to develop as an international center of excellence for wear- and friction-reducing coatings.

26th and 27th IAK meetings Tool Coatings and Cutting Materials
Berlin, Braunschweig – March, November 2012. In this year, the industry work group which is organized by the Fraunhofer Institute for Surface Engineering and Thin Films IST and the Department of Machine Tools and Factory Management IWF of the TU Berlin, met twice – on March 29, 2012 in Berlin at the Production Technology Center (PTZ) and for a second time at the Fraunhofer IST on November 14, 2012. Well-known experts from industry and research presented the most recent findings and developments for the manufacture and application of coated cutting tools and materials related to the topics of coatability of hard metals, pre- and post-treatment of tools, wood processing and new coating technologies.

Measurement Valley
The Fraunhofer IST Application Center for Plasma and Photonics, founded in 2012, presented itself to more than 50 members and friends of the research association Measurement Valley during an event held by the network at the HAWK in Göttingen. Here, representatives of local future-oriented companies were also able to gain an insight into the topics plasma components, hand-held devices and systems, laser plasma hybrid applications and plasma in the field of life sciences.

1. Bob Bond, Institute for Advanced Tooling, and Prof. (TUT) Wolfgang Diehl, Fraunhofer IST, with students of the master’s course “Surface Technology” at Tshwane University of Technology in Pretoria, South Africa.
2. Visitor from India: Prof. (TUT) Diehl, together with Prof. Dr. Szyszka and S. Gurram, presented the institute to consul general M. Subashini.

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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 Society 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 schoolchildren in order to arouse an enthusiasm for the natural sciences and engineering at an early age and to encourage the upcoming generation of scientists.
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 reinforce 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.

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 more than 80 research units in Germany, including 60 Fraunhofer Institutes. The majority of the more than 20,000 staff are qualified scientists and engineers, who work with an annual research budget of €1.8 billion. Of this sum, more than €1.5 billion is generated through contract research. More than 70 percent of the Fraunhofer-Gesellschaft’s contract research revenue is derived from contracts with industry and from publicly financed research projects. Almost 30 percent is contributed by the German federal and Länder 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.

Affiliated international research centers and representative offices provide contact with the regions of 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 reinforce 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 FOR LIGHT & SURFACES

Competence by networking
Six Fraunhofer institutes cooperate in the Fraunhofer Group for 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
- Surface and coating functionalization
- Laser-based manufacturing processes
- Laser development and nonlinear optics
- Materials in optics and photonics
- Microassembly and system integration
- Micro and nano technology
- Carbon technology
- Measurement methods and characterization
- Ultra precision engineering
- Material technology
- Plasma and electron beam sources

Fraunhofer Institute for Electron Beam and Plasma Technology FEP, Dresden
Electron beam technology, pulse magnetron sputtering and plasma activated high-rate deposition are the core areas of expertise of Fraunhofer FEP. Our business units include vacuum coating, surface modification and treatment with electrons and plasmas. Besides developing layer systems, products and technologies, another main area of work is the scale-up of technologies for coating and treatment of larger areas at high productivity. Our technologies and processes are applied in the fields of mechanical engineering, solar energy, biomedical engineering, environment and energy, for architecture and opto-mechanical precision systems.

Fraunhofer Institute for Laser Technology ILT, Aachen
The Fraunhofer Institute for Laser Technology ILT is worldwide one of the most important development and contract research institutes of its specific field. Our technology areas cover the following topics: laser and optics, medical technology and biophotonics, laser measurement technology and laser materials 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.

Fraunhofer Institute for Surface Engineering and Thin Films IST, Braunschweig
As an industry oriented R&D service center, the Fraunhofer IST is pooling competencies in the areas film deposition, coating application, film characterization, and surface analysis. Scientists, engineers, and technicians are busy working to provide various types of surfaces with new or improved functions and, as a result, help create innovative marketable products. The institute’s business segments are: mechanical and automotive engineering, aerospace, tools, energy, glass and facade, optics, information and communication, life science and ecology.

Fraunhofer Institute for Physical Measurement Techniques IPM, Freiburg
Fraunhofer IPM develops and builds optical sensor and imaging systems. These mostly laser-based systems combine optical, mechanical, electronic and software components to create perfect solutions of robust design that are individually tailored to suit the conditions at the site of deployment. In the field of thermoelectrics, the institute has extensive know-how in materials research, simulation, and systems. Fraunhofer IPM also specializes in thin-film technologies for application in the production of materials, manufacturing processes and systems.

Fraunhofer Institute for Material and Beam Technology IWS, Dresden
The business areas joining, cutting and surface technology are the main foci of the Fraunhofer Institute for Material and Beam Technology IWS. The research and development activities base on a distinctive know-how in the field of material engineering and nanotechnology and include the possibility of material characterization. The IWS’s special feature is its expertise in combining its know-how with its extensive experience in developing system technologies within the field of film- and laser technology.

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ENCOURAGEMENT OF YOUNG TALENT AT THE FRAUNHOFER IST

The encouragement of young talent – for the Fraunhofer Institute for Surface Engineering and Thin Films (IST) this means arousing in the young an enthusiasm for science, dispersing their reservations about involvement, and getting them interested in industry-oriented research. Supporting and mentoring school-children with an interest in the fields of research carried out at the Fraunhofer IST is an important part of the institute’s work.

At the Fraunhofer IST great importance was attached in 2012 as well to the subject of encouraging young talent and this year too a large number of events were arranged for those still at school:

Pinut: practical courses in science and technology for high-school girls
With the aim of getting high-school girls in particular interested in studying science, the Fraunhofer IST in 2012 took on three high-school girls as part of the Pinut program sponsored by the Braunschweig Colleges Association. In the three-week practical course they got to know different divisions and departments of the Fraunhofer IST.

Day of the future for young men and women at the Fraunhofer IST
Every year the Fraunhofer IST together with the Fraunhofer WKI open their doors as part of the “Day of the future for young men and women” with the aim of arousing an enthusiasm for science in high-school boys and girls. Wearing lab coats and eye shields a total of twenty-seven high-school students were able to spend half an academic year at school: kids eager for knowledge – 21 girls and 6 boys – spent a whole day experiencing the fascinating daily research routines of the two Fraunhofer institutes. At the Fraunhofer IST they learnt how to pretreat plastic cars by the atmospheric-pressure plasma process and metallize them currentlessly with copper. This showed that this method can be used to uniformly modify the surface of three-dimensional components. In addition, plastic films were location-selectively functionalized and can thus form the basis of biosensors or flexible printed circuits. At the end of day the youngsters could take their coated films home with them and hopefully the scientific spark has also started a fire burning in a few of them.

KIWI vacation care
The KIWI Researcher Days for the Curious program organized by the Braunschweig House of Science and aimed at children during their school vacations has become a fine tradition this year at the Fraunhofer IST. Under the slogan “Plasma illuminates – on the track of thin films” around twenty children aged between 10 and 14 undertook an exciting journey in the Easter and autumn vacations into the world of surface engineering and thin films. They saw the Fraunhofer IST laboratories, enormous coating installations, yellow rooms and plasmas igniting. In a large number of tests, demonstrations and hands-on activities the youngsters learnt about where thin films are needed, why they often have to be so thin and how they can be produced.

Working with schools: practice physics at the Fraunhofer IST
As part of a work group at the Fraunhofer IST three high-school students were able to spend half an academic year making use of their knowledge of chemistry and physics in day-to-day research. Under the leadership of Kai Weigel, a scientist in the “New tribological coatings” department, they participated in the development, production and characterization of a hard-material coating for tools and mechanical engineering components – from preparation of the parts to analysis of results.

Fraunhofer trainee exchange
In October 2012 Yvonne Bruchmann, trainee physics lab assistant and deputy youth and trainee representative at the Fraunhofer IST, took part as one of two female test pilots in the new Fraunhofer in-house trainee exchange program which she had herself helped to start. The aim of trainee exchange is for young trainees who have already completed their intermediate examination to gain an insight into the work and main areas of research of a different Fraunhofer institute. They can thus expand knowledge in their own professional field, find their way around in a new environment and gather new experiences.

The idea of an exchange arose at a meeting of the Fraunhofer IST trainee representatives (GIAs). Yvonne Bruchmann worked for two weeks at a branch of the Fraunhofer Institute for Silicate Research (ISCI) in Würzburg where she became acquainted with new processes, measuring techniques and materials. For the weathering stands, she coated, for example, glass slides with different conservation paints and treated specimens in a flame-polishing oven. This IST trainee found the exchange a thrilling experience which she enthusiastically recommends: “You don’t just accumulate new experiences in your professional field and learn how to adjust to a new team and different ways of working but by going to work somewhere else you acquire a good measure of independence.” The trainee exchange program is currently still at the testing stage. Yvonne Bruchmann is taking an active part in expanding and shaping the program in which trainees at all Fraunhofer institutes will in future be able to participate.
INPLAS: THE INDUSTRIELLE PLASMA-oberflächenotechnik E. V. competence network

The INPLAS e. V. competence network has its offices at the Fraunhofer IST. As a competence network INPLAS is accredited at the Federal Ministry of Economics and Technology (BMWi) and at the end of 2012 already had 39 members – companies or institutions – with around 200 active individuals of whom 70% were from industry. INPLAS has been a member of the BMWi “go-cluster” program since 2012.

INPLAS in 2012 once again with numerous successful activities contributed to further strengthening plasma technology and raising its profile. The most important areas of work of the network are summarized below.

Development and conceptual design of new topics for research, 2012+ report

In 2012 INPLAS conducted a survey regarding plasma surface technology. The results of the survey were published to the community in the Plasma 2012+ report, evaluated in closed meetings and the first steps to be taken defined. INPLAS actively accompanies the development of new research proposal requests: the BMBF’s “The basis of photonics: functional surfaces and coatings” appeared at the end of the year.

Third International Conference on HIPIMS in Sheffield

In 2012 the third international conference on high power impulse magnetron sputtering (HIPIMS) was held in Sheffield. The conference is jointly organized by Sheffield Hallam University, the Fraunhofer IST and the INPLAS e. V. competence network and held in each of the locations in turn. In 2013 the conference will therefore return to Braunschweig. Attendees at the 4th HIPIMS conference on 12th – 13th June 2013 will thus be greeted in Braunschweig city hall.

Active work of the work groups

The “Combined surface technology” joint committee, consisting of DFO, DGO, EFDS and INPLAS, organized a first workshop on the subject of “Innovative coatings for wind power plants”. This was held on 16th October 2012 with around 70 participants at the Fraunhofer Forum in Berlin. In view of the fact that the materials currently used can often not be adequately protected against corrosive influences, the aim of the event was to provide and discuss new and application-oriented information about combination coatings as well as to address new research topics. The great interest of attendees in the new coating concepts and material combinations confirmed the rightness of the joint committee’s decision to continue with future-related topics in the field of combination coatings.

The Innovative Plasma Sources and Processes work group headed by Dr. Bernhard Cord of Singulus Technologies AG and the Tools work group headed by Dr. Jan Gäbler of the Fraunhofer IST in each case each met in 2012 and covered the following current topics:

- “Innovative plasma sources and processes” work group: PECVD processes, plasma modeling and 3D coating, round-robin test regarding “Stoichiometric Al2O3 coatings with different production methods”
- “Tools” work group: acquisition of the AiF project “Process optimization of innovative CVD-SiC diamond-coated cutting tools on the basis of improved analytical methods”

In November 2012 Hanno Paschke, Dortmunder Oberflächenzentrum DOC and the Fraunhofer IST, took over the leadership of the “Tools” work group.

Public relations

In 2012 INPLAS 2012 was actively involved in the organization for the following events among others:

- Annual conference of the Initiative Kompetenzzentren Deutschland
- 13th International Conference on Plasma Surface Engineering (PSE 2012)
- Plasma Germany 2012

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MEMBERSHIPS

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www.awtv.org

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

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

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

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

European Photocatalysis Federation EPF
www.photocatalysis-federation.eu

European Society for Precision Engineering and Nanotechnology (euspen)
www.euspen.eu

European Technology Platform for Micro- and NanoManufacturing (MINAM)
www.minamwebportal.eu

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

Forschungsvereinigung Räumliche Elektronische Baugruppen 3-D MID e. V.
www.faps.uni-erlangen.de

Fraunhofer-Allianz Photokatalyse
www.photokatalyse.fraunhofer.de

Fraunhofer-Allianz Reinigungschnik
www.allianz-reinigungstechnik.de

Fraunhofer-Allianz SysWasser
www.syswasser.de

Fraunhofer-Netzwerk Elektrochemie
www.elektrochemie.fraunhofer.de

Fraunhofer-Netzwerk Nachhaltigkeit
www.fraunhofer.nachhaltigkeit.de

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

German Flatpanel Display Forum DFF
www.displayforum.de

German Water Partnership
www.germanwaterpartnership.de

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

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

Kompetenznetz Industrie Plasma Oberflächenbearbeitung CC UPOB e. V.
www.uopdb.de

NANOfutures European Technology Integration and Innovation Platform (ETIP) in Nanotechnology
www.nanofutures2010.eu

Plasmarichtet GmbH – Kompetenzzentrum Optische Technologien
www.plasmarichtet.de

Plasma Deutschland e. V.
www.plasmarichtet.de

Zentrum für Mikroreproduktion e. V. (DeMPro)
www.microcompany.de

BOARD MEMBERSHIPS


Bandorf, R.: Forschungsvereinigung Räumliche Elektronische Baugruppen 3-D MID e. V., Mitglied.

Bandorf, R.: Humboldt Stiftung, Gutachter.

Bandorf, R.: International Conference on HPRMS, Conference Chairman.


Bandorf, R.: Society of Vacuum Coaters, Session Chairman.

Bandorf, R.: Society of Vacuum Coaters, Volunteer Mentor.

Bandorf, R.: Society of Vacuum Coaters, Dozent.

Bandorf, R.: Zentrum für Mikroproduktionstechnik e. V., Mitglied.


Brand, G.: Kompetenznetz Forchungsgesellschaft Dünne Schichten e. V. (EFDS), Mitglied des Vorstands.


Diehl, W.: Deutsche Forschungsgesellschaft für Oberflächenbehandlung DFO, stellvertretender Präsident.

Diehl, W.: Europäische Forschungsgesellschaft Dünne Schichten e. V. (EFDS), Mitglied des Vorstands.


Diehl, W.: Glass Performance Days (GPD), Mitglied des Advisory Boards.

Diehl, W.: Plasma Germany, Mitglied des Koordinierungsausschusses.


Diehl, W.: Society of Vacuum Coaters (SVC), Chairmen.

Diehl, W.: Society of Vacuum Coaters (SVC), Mitglied des »International Relations Committee«.

Diehl, W.: Technologie transferkreis ForschungsRegion Braunschweig, Mitglied.
Neumann, F.: European Photocatalysis Federation EF, Mitglied.
Neumann, F.: DIN Deutsches Institut für Normung e. V., Normenausschuss 062 Materialprüfung, Arbeitsausschuss NA 062-02-93 AA »Photokatalyse«, Leitung des Arbeitskreises »Photokatalytische Selbstreinigung«.
Paschke, H.: Regionale Netzwerk-Initiative »In|Die RegionRuhr«, Arbeitsgruppenleiter Werkzeuge.
Publications

by pulsed reactive magnetron sputtering. In: Society of Vacuum

Bruns, S.; Vergöhl, M.: Mixed oxides for ultraviolet coatings prepared

Large-Area or High-Volume Products; June 24

Coatings on Glass and Plastics: Proceedings; Advanced Coatings for

metallic targets. In: Thin solid films 520 (2012), 12, pp. 4122

Bruns, S.; Vergöhl, M.; Werner, O.; Wallendorf, T.: High rate depositi-

and brittle materials. In: 3rd International Conference on NanoManu-

Gäbler, J.: CVD diamond grinding tools for precision grinding of hard

Brinksmeier, E.; Riemer, O.; Antsupov, G.; Rickens, K.; Meiners, K.;

(DCMSX-4). In: Surface and coatings technology 207 (2012),

suitable hard coatings on nickel-based single-crystal superalloy


Intelligence 2012 (SYSINT2012); Garbsen, Germany, June 27

challenges for product and production engineering: proceedings

Thin film sensors for condition monitoring in ball screw drives.

Biehl, S.; Staufenbiel, S.; Recknagel, S.; Denkena, B.; Bertram, O.;

Thin film sensors for condition monitoring in ball screw drives. In: Material-

koaps (2012), 1, S. 17.

Bielt, S.; Staufenbiel, S.; Recknagel, S.; Denkena, B.; Bertam, O.;

Thin film sensors for condition monitoring in ball screw drives. In: Material-

koaps (2012), 1, S. 17.

Bielt, S.; Staufenbiel, S.; Recknagel, S.; Denkena, B.; Bertam, O.;

Thick film sensors for condition monitoring in ball screw drives. In: Material-

koaps (2012), 1, S. 17.
Publications


Brand, H.: Optimized plasma nitriding processes for efficient wear

SVC, 2012, pp. 274


Publications


Sittinger, V.; Bandorf, R.; Szyszka, B.; Brauer, G.: HIPIMS – Applications and requirements (Talk), PE2 2012 Conference, Zielonka, Poland, February 2012.


Thomas, M.; von Hausen, M.; Maier, A.; Eggert, G.: Remove of silver tarnish films by using atmospheric-pressure plasma jets (Poster), 13th International Conference on Plasma Surface Engineering, Garmisch-Partenkirchen, Germany, September 2012.


DIPLOMA THESIS / MASTER’S THESIS


BACHELOR’S THESIS


PATENT APPLICATIONS
