Fraunhofer IST

FRAUNHOFER INSTITUTE FOR SURFACE ENGINEERING AND THIN FILMS IST

ANNUAL REPORT 2018

ANNUAL REPORT
2018

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FOREWORD

1 *On the left: director Prof. Dr. Günter Bräuer, on the right: director Prof. Dr. Christoph Herrmann.*

Ladies and gentlemen,

the year 2018 was a very successful year for the Fraunhofer Institute for Surface Engineering and Thin Films IST in many ways with various innovative developments and special events. We provide you with a selection of the most important events and latest research developments of the Fraunhofer IST in the annual report at hand.

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

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

Prof. Dr. Günter Bräuer

Prof. Dr. Christoph Herrmann

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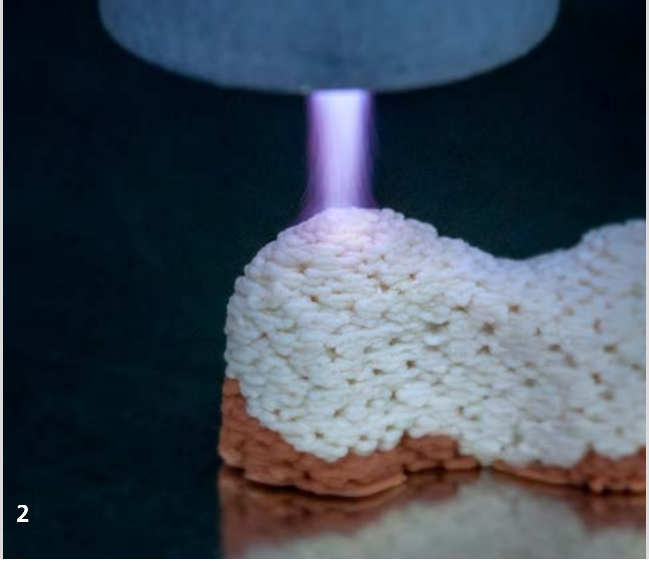

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2018 IN RETROSPECT

Whilst the following lines should actually cover the highlights of the Institute's work in 2018, the clock is initially being turned back to April 3rd, 2014. On this day, ESA launched the observation satellite "Sentinel 1A" into space. The large radar antenna for this and the following satellites of the Sentinel series originate from Braunschweig, and with "1A", coatings from the Fraunhofer IST left earth for the first time. In the meantime, they have become established in space. The October 20th, 2018 then set a further milestone along the pathway spreading our layers in space. In the early hours of the morning, the BepiColombo space probe began its lonely seven-year journey to Mercury. To protect the probe with its sensitive instruments from the extreme temperatures of between -173 °C and +430 °C, it is clad with cooling fins which are made from titanium and coated with a copper-silver system. A combination of PVD and electroplating was used. Such hybrid processes count among the strengths of our institute.

Towards the end of the year under review, the trade press presented a process entitled "Precisely fitting bone implants from the printer" with which, in the future, 3D printing will be utilized in order to produce bone implants which are tailored to specific patient requirements. The process is being developed at the Fraunhofer IST in collaboration with European partners. Tumor diseases, infections or severe fractures can necessitate the surgical removal of bone and the use of implants. During the printing process, the individual layers are treated with a cold plasma jet in order to support the growth of bone-forming cells on the surface and to promote the smooth ingrowth of the implant.

From May 2019, a new system of units is to enter into force worldwide, consisting solely of natural constants. In particular, the "problem child" of the metrology institutes, the primary kilogram, whose mass appears to constantly drift, will then be decommissioned after 130 years of service. It will be replaced by a silicon sphere whose atoms have been counted. For a number of years, we have been working together with the Physikalisch-Technische Bundesanstalt (National Metrology Institute of Germany, PTB) on a wafer-thin layer which should protect the oxygen-affine sphere material against corrosion.

Mathematics, engineering science, natural science and technology – the German terms for these fields result in the abbreviation MINT. From September 24th to 26th, the Science Campus took place at four Fraunhofer institutes in Braunschweig and Hanover. Through the demonstration of diverse fields of application in layer and surface technology, the Fraunhofer IST provided a contribution towards inspiring female students and graduates of MINT subjects as regards working in applied research.

The puzzle which forms our international activities has been extended through the addition of further elements. Clean water for the rural regions of South Africa is the goal of an EU-funded project in which a number of Fraunhofer institutes are cooperating with South African partners. A corresponding demonstrator for water treatment is already being utilized. In 2018, the basis was created for a project center at the University of Stellenbosch in which, in addition to the IST, the Fraunhofer Institutes IGB, IOSB and ISE are participating.

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A further look at new markets is being directed towards Taiwan. On June 1st , 2018, the partnership between the IST and the Feng Chia University FCU in Taichung which had existed since 2014 was officially sealed through a cooperation agreement. In a supplementary step, Professor Ju-Liang He from the Department of Materials Science and Engineering, together with Dr. Ralf Bandorf from the IST, opened the joint Institute of Plasma IoP. Significant research activities will focus here on highly ionized plasmas for coating. Professor He is thereby also opening doors to Taiwanese industrial partners.

Since November 1st, Prof. Dr. Christoph Herrmann is a member of the Fraunhofer IST Institute management. As Head of the TU Institute of Machine Tools and Production Technology IWF, he simultaneously remains a member of the Department of Mechanical Engineering at the TU Braunschweig. With the appointment of Prof. Herrmann, the IST is doubly networked with the TU. He brings with him a number of new topics which will enhance the IST's expertise, particularly in the fields of "Product and production systems" and "Life Cycle Engineering".

Sincerely yours Günter Bräuer

1 *Cooling fins made of titanium for the Merkury mission BepiColombo.*

2 *Plasmajet for coating with functional groups.*

3 *The participants of the Science Campus at the Fraunhofer IST.*

BOARD OF TRUSTEES

FROM THE BOARD OF TRUSTEES

Digital evolution is a challenge as well as an opportunity for our society, politics, the economy, science and also for the Fraunhofer Institute for Surface Engineering and Thin Films IST.

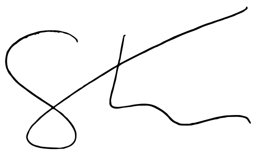
Since its foundation, the Fraunhofer IST has stood for, amongst other things, diamond-like carbon films. The demand for wear-resistant and low-friction coatings for a diversity of applications in a wide variety of sectors continues unabated. DLC films correspondingly play an integral role in the IST portfolio. The Institute recognized at an early stage that these films are capable of more: due to their piezoresistive properties, they are suitable for the construction of sensors for force and pressure measurement.

With thin-film sensor technology, the Institute has a future-oriented field of research at its disposal which also offers innovative solutions for problems arising in the course of digitization and Industry 4.0. The focus is thereby directed on a multifunctional thin-film system with which pressure and temperature distribution can be measured locally, even on complex surfaces, e.g. directly on components or tools. The examples are diverse and the results fascinating: from the intelligent washer through real-time data acquisition in injection molding and on to the utilization of a sensor layer on a kingpin in order to reduce energy consumption, carbon dioxide emissions, noise and brake dust.

The Board of Trustees is following the work on thin-film sensor technology with great interest, particularly in view of the envisaged industrial implementation. This is, however, only one of many exciting topics which the IST has propelled forwards in the year under review and which will await us in the coming year.

In Professor Dr. Christoph Herrmann, who was designated as part of the succession regulation for Professor Bräuer, an additional Institute Director has been appointed who introduces a whole series of new topics which place the IST in an excellent starting position for digital evolution.

I am very much looking forward to this and would like to wish all employees and the Institute management every success for the year 2019.



Dr. Gerrit van der Kolk
IonBond Netherlands BV

OUTSTANDING COLLABORATION

Stellenbosch University (SU) is a research-intensive institution with 33 percent of its 32,000 students enrolled in postgraduate programs. The University has a long history of international collaboration and has an excellent success rate in securing research funding for joint projects with European partners.

SU recognizes Fraunhofer-Gesellschaft as a world leader in technology development and has collaborated with various Fraunhofer institutes in the past. South Africa is a water-scarce country, and the recent water crisis in the Western Cape showed the real possibility that Cape Town could experience a "Day Zero" when taps would run dry. This is a threat to a number of other cities, not only in South Africa but around the world. Strategies enabling water conservation and improved technologies to treat water for re-use are essential to the mitigation of this challenge. The Stellenbosch University Water Institute (SUWI), therefore values the broad range of expertise that Fraunhofer's Water Systems Alliance (SysWasser) offer to assist in our goal to find sustainable solutions to water supply.

Since the first collaborative workshop between SUWI and SysWasser in 2016, in which IST took a strong lead, our cooperation with the IST developed into a strong partnership. A good example is the funding of the SafeWaterAfrica project by "EU Horizon2020" that involves research and further development of an autonomous "Made in Africa" water treatment system for rural and peri urban areas.

The integrated Fraunhofer IST technology of electrochemical oxidation with diamond electrodes shows tremendous promise as an efficient way to degrade emerging organic contaminants of concern as well as killing of microbial contaminants.

The professional way in which the IST leads a strong consortium from five countries to assemble a decentralized system that can operate in isolated rural areas will ensure that this project leaves a legacy in this critically important area. It is also worth to note, that in addition to the technical innovation, our IST colleagues also recognized the need to incorporate a social dimension to the project to ensure acceptance in the rural communities where the technology will have the most impact – an area often neglected in international projects.

With the "SafeWaterAfrica" project as basis, IST took the initiative and leadership to initiate an ICON project between SU and four SysWasser Institutes. Through the ICON Program, Fraunhofer Headquarters supports the Gesellschaft's Institutes in the initial phase of an envisaged long term collaboration with research organizations outside Germany.

We are thus excited about this opportunity, and based on our positive experience with IST to date, SU saw the strategic value in matching an equivalent to the 1.5 million euros committed by Fraunhofer to this project that will combine Fraunhofer and SU technologies in the area of water supply and management.

PhD. Gideon M. Wolfaardt
Stellenbosch University Water Institute

FRAUNHOFER IST

INSTITUTE PROFILE

The Fraunhofer Institute for Surface Engineering and Thin Films IST in Braunschweig is an innovative partner for research and development in surface technology, with expertise in the associated product and production systems. The institute focuses on the following business fields:

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

Around 120 employees work together with customers from industry and research to develop customized and sustainable solutions: from prototypes through economic production scenarios to upscaling to industrial magnitudes – and all this whilst maintaining closed material and substance cycles. In addition to application-oriented research and development, scientific principles are also researched within various collaborations with universities and research institutions.

Coating and surface technology is the key to innovative products and systems: Through modification, patterning and coating of the surface, a wide range of functions and functionalities can be realized. Friction reduction, abrasion and corrosion protection, sensor features or optical properties are just a few examples.

Available technologies for this purpose include among others:

- Electrochemical processes, in particular electroplating,
- atmospheric pressure processes,
- low-pressure plasma processes with the main focus on magnetron sputtering, highly ionized plasmas and plasma-activated vapor deposition (PECVD) as well as
- chemical vapor deposition with the main focus on hot-wire CVD.

One of the Institute's particularly strong points is its ability to create the optimum process chain for the respective task on the basis of a broad spectrum of processes and coating materials.

The Fraunhofer IST not only has excellent capabilities in surface analysis using the very latest equipment but has also accumulated extensive experience in the modeling and simulation of both product properties and the associated processes and production systems.

At the site in Braunschweig the Institute has an office and laboratory area of more than 4000 square meters. In addition, the new building of the Application Center for Plasma and Photonics provides 1500 square meters of office and laboratory area in Göttingen.

From 2019, the Fraunhofer IST, in collaboration with the Fraunhofer institutes for Ceramic Technologies and Systems IKTS and for Manufacturing Technology and Advanced Materials IFAM, will participate in the Project Center for Energy Storage and Management Systems ZESS, which opened on February 7th, 2019. During the transition phase, laboratory space at the Niedersächsisches Forschungszentrum Fahrzeugtechnik (Lower Saxony research center for vehicle technology, NFF) and offices in the Lilienthalhaus at the Research Airport Braunschweig will be rented.

The range of services offered by the Fraunhofer IST is complemented by the expertise of other institutes within the Fraunhofer Group "Light & Surfaces" as well as by the competencies of the Institutes for Surface Technology IOT and for Machine Tools and Production Technology IWF of the TU Braunschweig, which are simultaneously led by the managers of the IST Prof. Günter Bräuer and Prof. Christoph Herrmann.

Many projects are funded through public resources of the state of Lower Saxony, the federal government, the European Union and other institutions.

THE INSTITUTE IN FIGURES

Employee development

In 2018, the period under review, the Fraunhofer Institute for Surface Engineering and Thin Films IST had 115 employees of which 45 percent are scientific personnel, doctoral candidates and engineers. Research activities were supported by technical and commercial staff as well as a large number of graduates and student assistants. Training opportunities in the vocational fields of galvanics, physics and information technology were taken up.

Operating budget

In 2018, the operating budget resulted in total of €12.3 million. The ratio of material costs to personnel costs was 30 to 70 percent. Thus, the personnel costs amounted to €8.1 million.

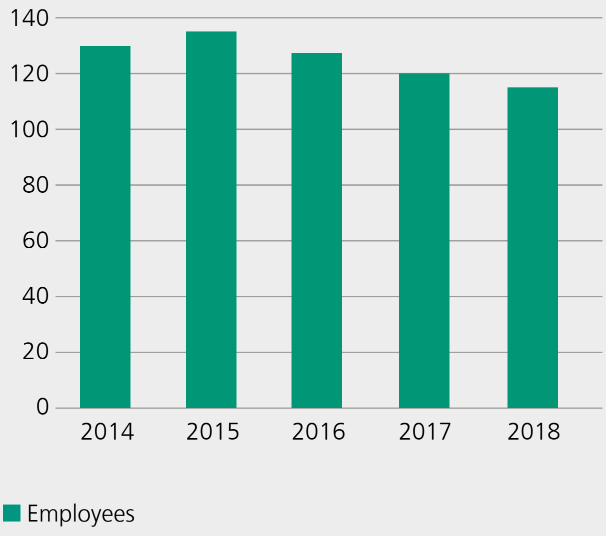
Earning structure

Industrial revenues amounted to €4.8 million, whilst public funding lay at €2.8 million. In total, the institute has achieved external revenue amounting to €7.6 million.

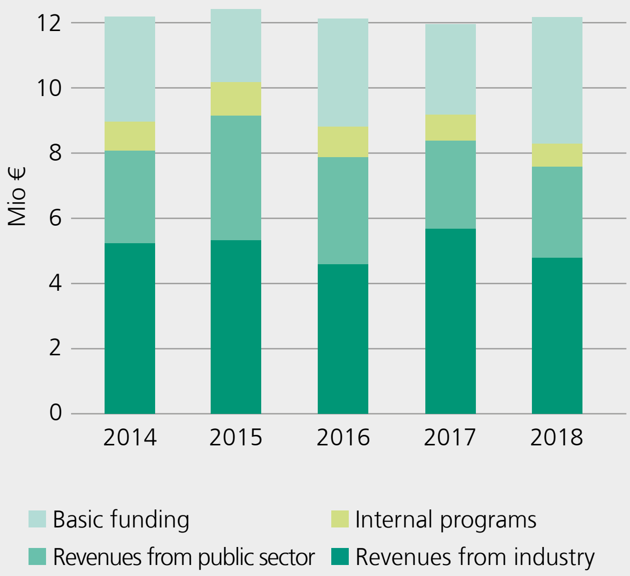
Investments

All in all, the Fraunhofer IST dispensed on investment some €310,000. Approximate €60,000 could be invested through external project funds. €160,000 can be attributed to normal investments. €65,000 were used for strategic investments. This means for the Fraunhofer IST an overall budget (B+I) totaling €12.3 million.

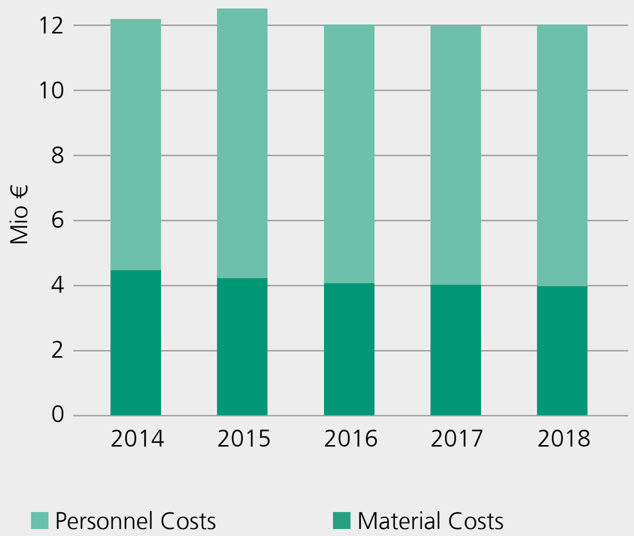
Employee development



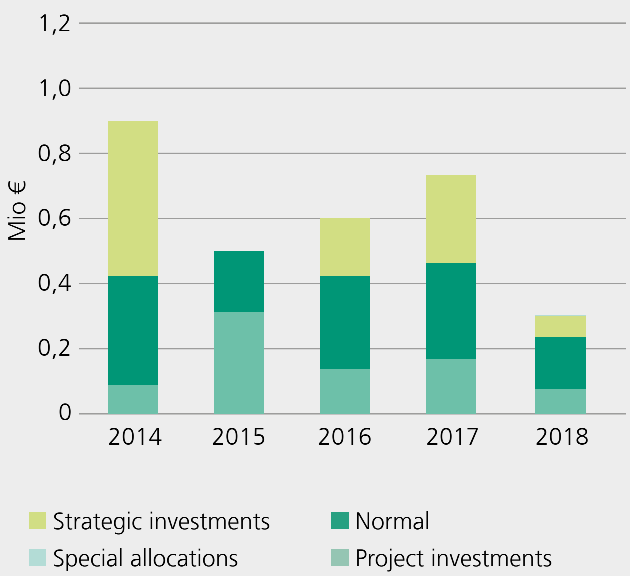
Earning structure



Operating budget



Investments



YOUR CONTACT PERSON

INSTITUTE MANAGEMENT AND ADMINISTRATION

Institute management

Prof. Dr. Günter Bräuer[1]
Phone: +49 531 2155-500
guenter.braeuer@ist.fraunhofer.de

Prof. Dr.-Ing. Christoph Herrmann[2]
Extension: 503
christoph.herrmann@ist.fraunhofer.de

Research strategy and coordination
Deputy director

Dr. Lothar Schäfer[3]
Extension: 520
lothar.schaefer@ist.fraunhofer.de

Administration

Ulrike Holzhauer[4]
Extension: 220
ulrike.holzhauer@ist.fraunhofer.de

Marketing and Communications

Dr. Simone Kondruweit[5]
Extension: 535
simone.kondruweit@ist.fraunhofer.de

Business development

Dr. Guido Hora[6]
Extension: 373
guido.hora@ist.fraunhofer.de

HEADS OF DEPARTMENT AND GROUP MANAGERS

Low pressure plasma processes

Dr. Michael Vergöhl[7]
Extension: 640
michael.vergoehl@ist.fraunhofer.de
Optical coating systems | Process engineering | Materials engineering

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

Highly ionized plasmas and PECVD
Dr.-Ing. Ralf Bandorf[8]
Extension: 602
ralf.bandorf@ist.fraunhofer.de
Multifunctional coatings with sensors | High Power Impulse Magnetron Sputtering (HPIMS) | Micro tribology | Electrical coatings | Hollow cathode processes (HKV, GFS) | Plasma-enhanced CVD (PECVD)

Simulation
Dr. Andreas Pflug[9]
Extension: 629
andreas.pflug@ist.fraunhofer.de
Simulation of plants, processes and coating layer properties | Model-based interpretation of coating processes

Chemical vapor deposition

Dr. Volker Sittinger[10]
Extension: 512
volker.sittinger@ist.fraunhofer.de

Dr. Markus Höfer[11]
Senior Scientist
Extension: 620
markus.hoefer@ist.fraunhofer.de

Atomic layer deposition
Product-related system construction | Coating and process development | Highly compliant coatings of 3D structures

Hot-wire CVD
Dr. Christian Stein[12]
Extension: 647
christian.stein@ist.fraunhofer.de
Diamond coatings and silicon-based coatings | Tool and component coatings for extreme wear resistance | Diamond coated ceramics DiaCer® | Electrical applications for semiconductors, barriers | Antireflective

Photo and electrochemical environmental engineering
Test engineering | Photocatalysis | Diamond electrodes for electrochemical water treatment | Air, water and self-cleaning | Product evaluation and efficiency determination

Atmospheric pressure processes

Dr. Michael Thomas[13]
Extension: 525
michael.thomas@ist.fraunhofer.de

Electrochemical processes

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

Atmospheric pressure plasma processes

Dr. Kristina Lachmann[14]
Extension: 683
kristina.lachmann@ist.fraunhofer.de

Microplasmas | Low temperature bonding | Surface functionalization and coating | Plasma printing

Surface chemistry

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

Application center for plasma and photonics

Dr.-Ing. Jochen Brand[15]
Extension: 600
jochen.brand@ist.fraunhofer.de

Prof. Dr. Wolfgang Viöl[16]
Phone: +49 551 3705-218
wolfgang.vioel@hawk-hhg.de

Plasma particle coating and cold plasma spraying | Plasma sources conception | Plasma treatment of natural products | Laser plasma hybrid technology for micro structures and surface modification | Laser technique for material treatment and characterization

Center for tribological coatings

Dr.-Ing. Jochen Brand[15]
Extension: 600
jochen.brand@ist.fraunhofer.de

System analysis and system optimization | Tribological coatings | Tribotesting | Device conceptions

Micro and sensor technology

Dr.-Ing. Saskia Biehl[17]
Extension: 604
saskia.biehl@ist.fraunhofer.de

Wear-resistant thin-film sensors for temperature, force, wear and distance measurement | Microstructuring 2D and 3D of functional coatings | Sensor modules for forming processes | Sensorized washer systems

Tribological Systems

Dr.-Ing. Martin Keunecke[18]
Extension: 652
martin.keunecke@ist.fraunhofer.de

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

Dortmunder surface technology center (DOC)

Dipl.-Ing. Hanno Paschke[19]
Phone: +49 231 844 5453
hanno.paschke@ist.fraunhofer.de

Duplex treatment through plasma nitriding and PACVD technology | Boracic hard coatings | Tool coating | Coatings for hot forming | Coatings for industrial knifes | Fuel cells

Fraunhofer Project Center for Energy Storage and Systems ZESS

Prof. Dr.-Ing. Arno Kwade[20]
Phone: +49 531 391-9610
arno.kwade@ist.fraunhofer.de
Development of mobile and stationary energy storage devices and systems | Development and scaling of process technologies | Production of solid-state batteries

Process Technology and Production Engineering

Dr.-Ing. Marko Eichler[21]
Phone: +49 531 2155-636
marko.eichler@ist.fraunhofer.de
Product and production systems | Energy starage development and production engineering | Production Engineering | Sustainable Factory Systems | Life Cycle Management

Energy Storage Development and Production Engineering

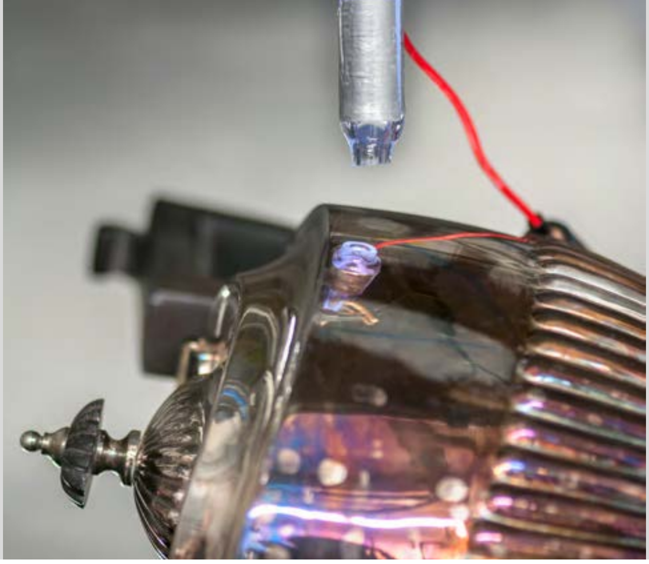
Dipl.-Ing. Sabrina Zellmer[22]
Extension: 528
sabrina.zellmer@ist.fraunhofer.de
Coating and functionalization of surfaces and particles | Production of anode/cathode materials and solid-state electrolytes | Formulation strategies for solid-state batteries | Electrode production | Characterization from material to cell

Sustainable Factory Systems and Life Cycle Management

M.Sc. Stefan Blume[23]
Extension: 532
stefan.blume@ist.fraunhofer.de
Battery cell manufacture | Data mining and data analytics | Model-based planning, simulation and operation of battery production systems | Cyber-physical production systems | Economic and ecological life cycle analyses

Analysis and Quality Assurance

Dr. Kirsten Schiffmann[24]
Extension: 577
kirsten.schiffmann@ist.fraunhofer.de
Chemical microscopy and surface analysis | Microscopy and crystal structure | Test engineering | Costumer specific test engineering | Order investigation



THE SCOPE OF RESEARCH AND SERVICES

Pretreatment –
We clean surfaces

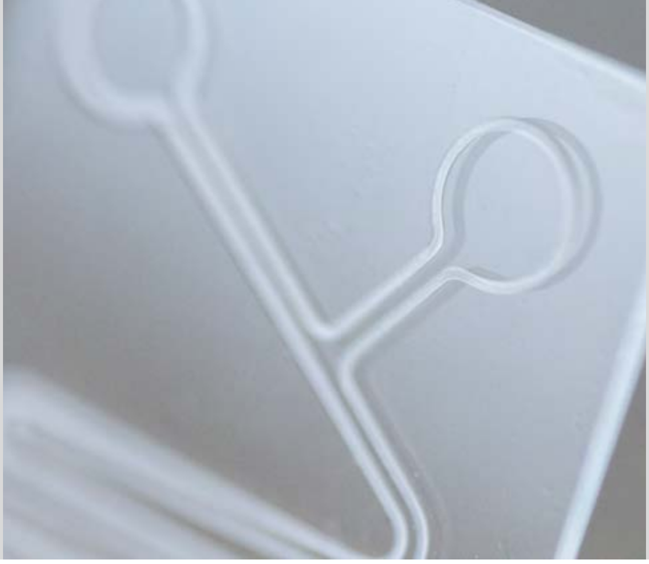
Successful coating processes imply a proper surface pretreatment. Therefore we offer:

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

Modification and Coating –
We develop processes and coating systems

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

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



Testing and Characterization –
We ensure quality

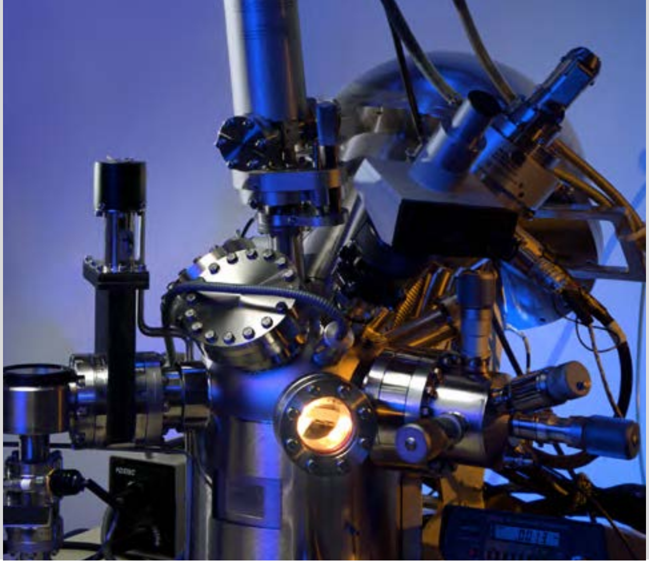
A fast and reliable analysis and quality control is the prerequisite for a successful coating development. We offer our customers:

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

Application –
We transfer research results to production level

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

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



ANALYSIS AND QUALITY ASSURANCE

Chemical and structural analysis

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

Microscopy

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

Mechanical tests

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

Measurement of optical properties

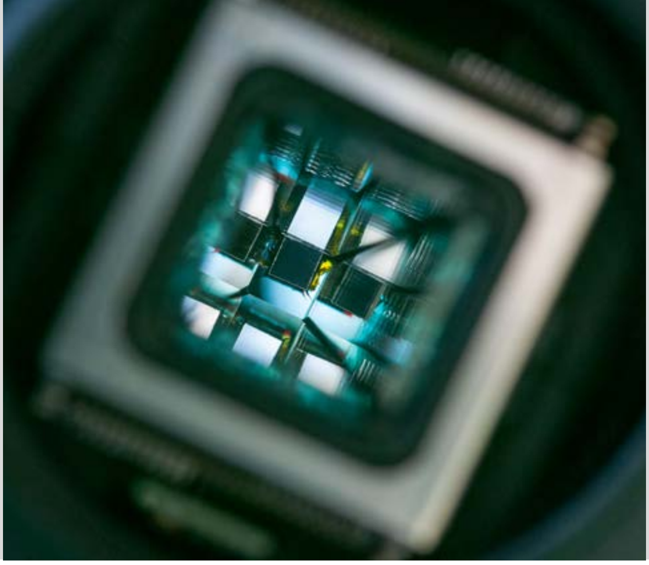
- IR-UV-visible spectrometry
- Ellipsometry
- Colorimetry
- Angular-resolved scattered light measurement (ARS)
- Integral scattered light measurement (Haze)

Measurement of friction, wear and corrosion

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

Specialized measurement stations and methods

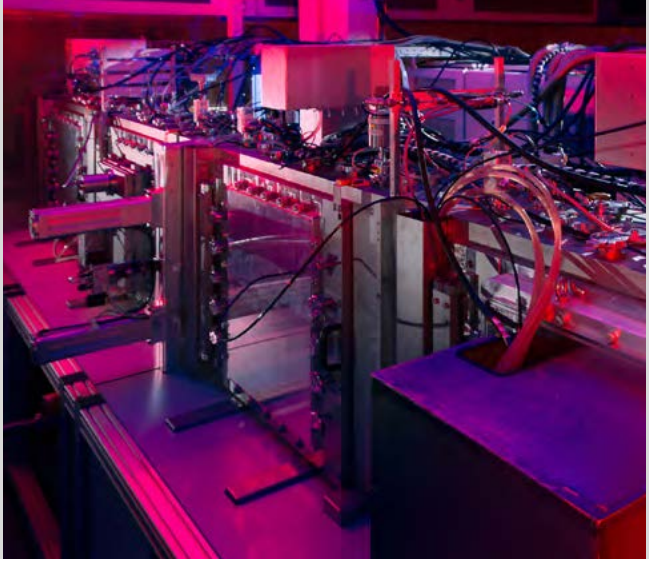
- Characterization of solar cells
- Measuring station for photocatalytic activity
- Contact angle measurement (surface energy)
- Measuring systems for electrical and magnetic coating properties (e. g. Hall, Seebeck, conductivity, vibration magnetrometer VSM)



- Test systems for electrochemical wastewater treatment
- Measuring stations for the characterization of piezoresistive and thermoresistive sensor behavior
- Biochip reader for fluorescence analysis
- Layer mapping system (0.6 x 0.6 m^2) for reflection, transmission, Haze and Raman measurement
- In-situ bondenergy measurement
- Magnetic characterization (vibration magnetrometer VSM)
- Electrochemical measurement stations (CV measurement)
- Wet chemical rapid tests: colorimetrical determination of ion and molecule concentrations
- Weathering tests: cyclical simulation of UV and rain exposition

Plasma diagnostics

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



SPECIAL EQUIPMENT

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

- Anodizing plant (11 active baths with a volume of each 140 l and 2 anodizing baths with a volume of each 350 l)
- 15-stage cleaning unit for surface cleaning on aqueous basis
- Clean room – large area coating (25 m^2)
- Clean room – sensor technology (35 m^2)
- Laser structuring laboratory (17 m^2)
- Mobile atmospheric pressure plasma sources
- Nanosecond dye laser (Nd: YAG-Laser)
- CO_2-laser and Excimer-Laser
- EUV spectrography
- Semiconductor laser
- Picosecond laser

SUSTAINABLE SOLUTIONS FROM THE FRAUNHOFER IST

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

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

Innovative materials

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

Material efficiency

- In a combined process of atmospheric pressure plasma processes and electrochemical processes precious metals are applied to selected areas.
- Working materials with new properties are discovered by combining different materials or layer and basic body.
- Modules with sensory thin-film systems are integrated in thermoforming systems and propulsion machinery to ensure efficient transformation and machining of components.
- Lower energy consumption due to the erosion protection of aero engines: very hard multilayer coatings of ceramic and metal prevent excessive fuel consumption and falling efficiency levels.
- Broader and improved range of applications for lightweight components by means of wear-resistant, friction-reducing coatings which also protect against corrosion.
- Reduced solar radiation in buildings by the use of electrochromic windows.
- “Data mining” in production – from data collection to evaluation using machine learning methods – enables the identification of “drivers” in terms of energy and resource consumption.

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.
- Lifecycle analyzes are carried out in order to holistically evaluate and improve the economic and ecological sustainability of products.
- The development of cyber-physical production systems (CPPS) enables a more sustainable design and control of production. By using "digital twins" design alternatives can be analyzed in real time.
- Multi-scale simulation from the material to the factory roof: By coupling specific simulation models, interactions between the product and the production system makes them assessable and potential savings become visible.

Clean environment and health

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

Mobility in the future

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

MECHANICAL ENGINEERING, TOOLS AND AUTOMOTIVE TECHNOLOGY

In the business unit "Mechanical Engineering, Tools and Automotive Technology", coating systems for friction reduction as well as for wear and corrosion protection are developed and optimized for specific applications. This encompasses the entire process: from cleaning and pretreatment by means of structuring and diffusion treatments, to coating and process development – including analysis and simulation – and on to integration into industrial applications. With a comprehensive portfolio of coating and treatment processes, the Fraunhofer IST is active in both industrial and public projects in a diverse range of application areas such as:

- DLC and hard coatings for motor, drive and bearing components
- Tools for the ecologically and economically optimized processing of lightweight materials such as aluminum, titanium, ultra-high-strength steels, polymers, etc.
- Highly corrosion-resistant and wear-resistant carbon coating systems for sealing applications
- Coating of original tooling and forming dies
- Surfaces for batteries and fuel cells
- Wear-resistant non-stick and antifouling coatings for the food and pharmaceutical industries

Functional surfaces for the automotive industry.

The advancing digitization of production processes and products also forms the focus of research activities at the Fraunhofer IST. Sensor-integrated surfaces enable the direct ascertainment of widely varying process parameters such as temperature, force, wear, and position in the production processes, thereby forming the fundament for the consistent digitization and flexibilization of autonomous production facilities. So-called "smart" tool surfaces offer new possibilities for predictive maintenance and, consequently, for increasing the productivity of manufacturing processes.

Sensory surfaces are developed and successfully deployed at the Fraunhofer IST in a diverse range of safety-relevant applications. Examples include:

- Sensory washers for continuous force monitoring
- Pressure and temperature thin-film sensors for highly stressed tools and components
- Magnetic functional coatings for high-precision positioning systems and magnetic labels

Furthermore, the additive production of polymeric and metallic workpieces offers versatile starting points for surface technology along the process chain. The activities of the Fraunhofer IST encompass the coating of powders in order to improve their processing, the application of atmospheric plasmas in the printing process in order to locally optimize the component properties, and subsequent surface treatment for the creation of functional surfaces.

In addition to coating manufacturers, our customers primarily include companies from the automotive industry, tool manufacturers and users as well as coating users from all fields of mechanical engineering.

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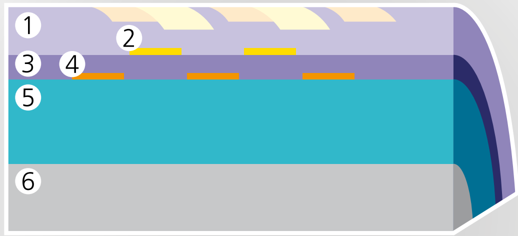

1. Insulating and wear-protection layer (3 µm)
2. Temperature meander structure (0.2 µm)
3. Insulating and wear-protection layer (1 µm)
4. Electrode structure Cr (0.2 µm)
5. DiaForce® (6 µm)
6. Steel base body

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DEVELOPMENT OF A SENSORY KINGPIN

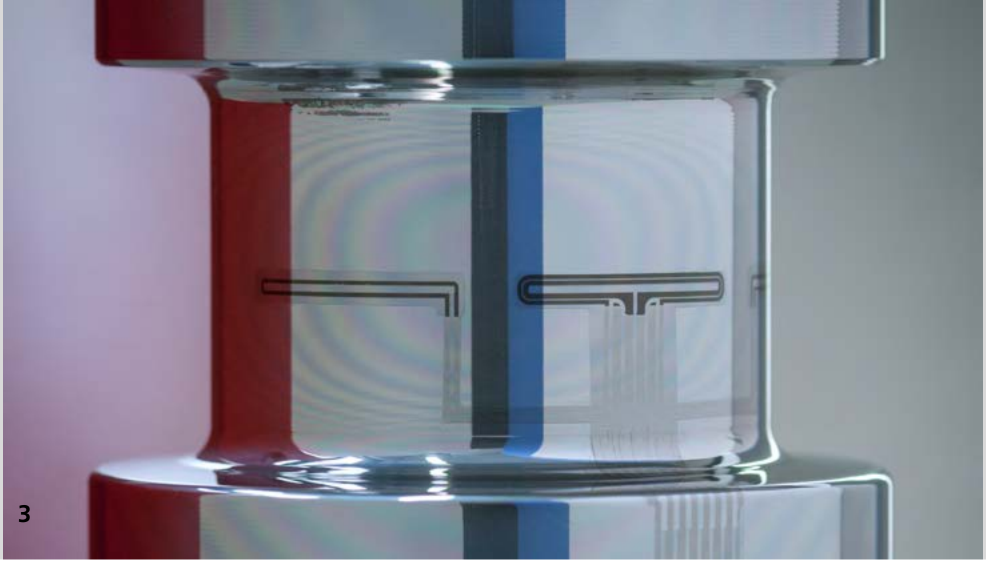
With the objective of reducing the energy consumption as well as CO_2, noise, and brake dust emissions when using vehicle trailers, an innovative propulsion and control system has been developed for vehicle trailers as part of the "ev (electric vehicle) Trailer" project funded by the BMWi. The outstanding feature is the manufacturer-independent autonomous mode of operation of the evTrailer, which functions with any conventional tractor unit. At the Fraunhofer IST, within the project a piezo-resistive thin-film system is used to measure force, this system is directly precipitated onto the complex shape of the mechanical connecting link between tractor unit and trailer, the so-called kingpin (see Figure 1). Interaction of the applied components, specifically force measurement sensors, electric powertrain module, traction battery, and battery management system, is ensured through intelligent control algorithms.

Task of the sensory kingpin

The sensory film system developed at the Fraunhofer IST for local tensile force measurement is precipitated and structured directly on the three-dimensional surface of a kingpin. With these measurement results, an adjustment occurs that should compensate the tensile force or shear force that occurs in the trailer coupling. This means that the energy generated by the braking power, which is recovered via the electric motors at downhill travel, and which is stored in batteries will, if needed i.e. for uphill travel or for acceleration processes, again be available to the vehicle as drive power. Depending on the load status and the control strategy, the tractor "feels" neither the pull nor the push of the attached evTrailer. Thus, the tractive unit is offloaded, which means that less energy is consumed and CO_2 emissions are minimized.

Development of the sensory kingpin

Within the project, the task of the Fraunhofer IST is the integration of the thin-film sensors for measuring the load and temperature distribution in the main load zone of the kingpin, which weighs 6 kg. For this, the film system presented in Figure 2 is precipitated and structured on the manually polished surface of the kingpin in such a manner that the measurement areas are located in the upper part. The conductive traces to the contact area must be routed over several edges, so that they can be arranged in the lower screw connection area. Figure 3 shows the complexity of the structuring, in which the photolithography and the wet-chemical etching are combined. The structures running horizontally will later be in direct contact with the locking hook of the fifth-wheel coupling and they will measure the forces occurring under strong frictional load. The meander-shaped structures measure temperature.



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1 *The kingpin connects the tractor to the trailer.*

2 *Schematic presentation of the film system.*

3 *Photolithographic structuring of the merely 200 nm thin chromium coating on the kingpin for the manufacturing of complexly routed conductive traces.*

Outlook

After the successful manufacturing of the multi-sensor thin-film system on the kingpin surface, the characteristic curves of the piezo-resistive and thermo-resistive sensor structures will be recorded and combined with the measurement technology of the project partner CuroCon GmbH. Then, the functionality of the thin-film system will be verified in test runs with a semitrailer from the company Wilhelm Schwarzmüller GmbH.

The project

The described results were achieved within the »evTrailer« project, in which the Fraunhofer IST takes part, together with the Fraunhofer Institute for Structural Durability and System Reliability (Fraunhofer-Institut für Betriebsfestigkeit und Systemzuverlässigkeit (LBF)), the Institute for Internal Combustion Engines and Powertrain Systems (Institut für Verbrennungskraftmaschinen und Fahrzeugantriebe (VKM)) at the Technical University of Darmstadt and the companies CuroCon GmbH and OSWALD Elektromotoren GmbH. The project is funded by the Federal Ministry for Economic Affairs and Energy (BMWi) and runs from 01/01/2016 to 12/31/2018.

CONTACT

Dr. Saskia Biehl
Phone +49 531 2155-604
saskia.biehl@ist.fraunhofer.de

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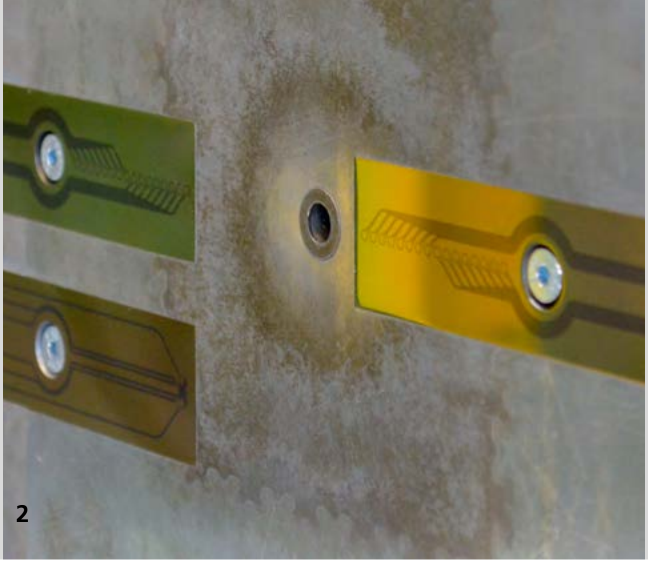

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INNOVATIVE SENSOR SYSTEMS FOR PRODUCTION MONITORING

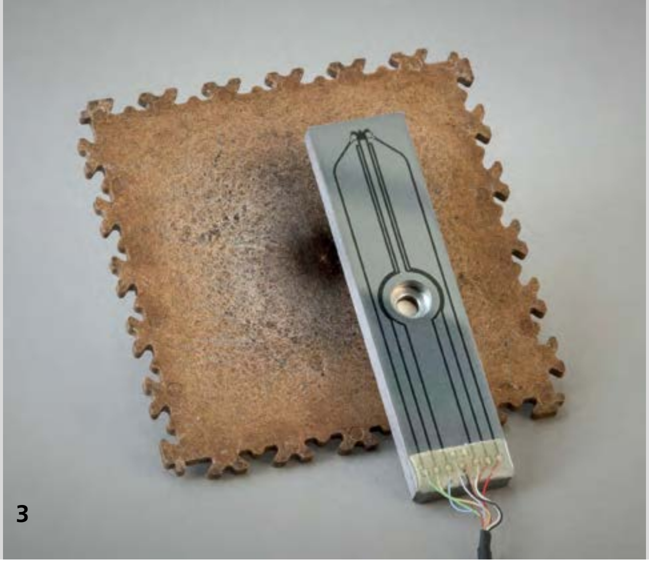
In addition to further developments in the field of data processing, powerful sensor systems for measurement data acquisition are also a factor of success for the fourth industrial revolution – Industry 4.0. The integration of commercial sensor systems within the most highly stressed zones of the components or tools is often particularly challenging. One alternative is offered by thin film sensor systems, which are applied directly to the surfaces of components or tools and can thus capture parameters such as strain and temperature distribution in direct contact with the work piece without necessitating changes to the design. Various application-specific sensor systems on components are being developed at Fraunhofer IST within the framework of several publically funded projects.

Multifunctional thin film sensors on bending and deep drawing tools

A multifunctional thin film sensor system on bending and deep drawing tools is being developed within the framework of the Cornet project "SensorFut". Particularly challenging was the fabrication of a wear-resistant thin film sensor system on a tool surface with complex curvatures, so that – as shown in Figure 1 – piezo-resistive sensor structures could be combined with thermo-resistive structures in the curved areas. This was achieved with a multifunctional film system which is based on the DiaForce® film, an amorphous hydrocarbon layer developed by Fraunhofer IST, which is very hard at 24 GPa and at the same time piezo-resistive. Complex structuring methods are used to produce sensor areas made up of chromium structures on the coated tool, which are then connected to the contacting pad via thin traces. At the same time, individual meander structures for temperature measurement are integrated into the film system between two electrical isolation layers.

Thin film sensors in injection molding machines

The multifunctional thin film sensor system described before is also used within the Cornet project "SmartNFR". The goal is to achieve more efficient fabrication of components made from natural fiber reinforced composites (NFR) through the use of wear-resistant thin film sensors in injection molding machines. Not only do these innovative composite materials exhibit new functionality with regard to color, strength, and weight, they are also recyclable. They have a broad range of applications, from lightweight design to the automotive industry and common everyday products such as flooring. In the course of the project, the mentioned multifunctional thin film sensor system was applied to steel inserts in order to measure the temperature distribution and to determine the flow behaviour in the form during the injection molding process. Three of these wear-resistant sensor modules were integrated into an injection molding plant at the Tomas Bata University in Zlin, which is used to fabricate floor panels (see Figure 2). The first successful test of the sensor system took place in direct contact with a polypropylene melt containing 30 percent wood fibers (see Figure 3).



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1 *Deep-drawing die with complete sensor system.*

2 *Injection molding integrated wear-resistant sensor modules.*

3 *Wood fiber reinforced injection molded part in contact with sensor module.*

The projects

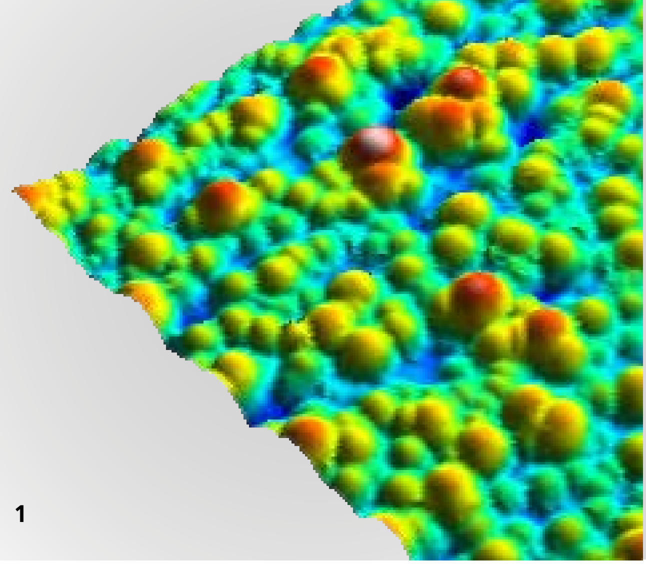
The described results were achieved within the course of two Cornet projects.

In the “SensoFut“ (Sensorized Future – Sensing of temperature and pressure in harsh environments) project, Fraunhofer IST worked together with the Fraunhofer Institute for Machine Tools and Forming Technology IWU and the Belgian research association Sirris. The project, which ran from 01/01/2013 to 30/06/2015, was funded by the Federal Ministry for Economic Affairs and Energy (BMWi) and the German Federation of Industrial Research Associations (AiF) within the framework of the 13th Cornet Program (Collective Research Networking).

The project “Smart NFR“ (Smart coating systems for process control and increased wear resistance in processing of natural fibre reinforced polymers), which Fraunhofer IST is working on in partnership with the Fraunhofer Institute for Machine Tools and Forming Technology IWU and the Czech university Tomas Bata in Zlin, is funded in the 19th Cornet Call (Collective Research Networking) by the Federal Ministry for Economic Affairs and Energy (BMWi) and the German Federation of Industrial Research Associations (AiF) and runs from 01/06/2016 to 30/11/2018.

CONTACT

Dr. Saskia Biehl
Phone +49 531 2155-604
saskia.biehl@ist.fraunhofer.de



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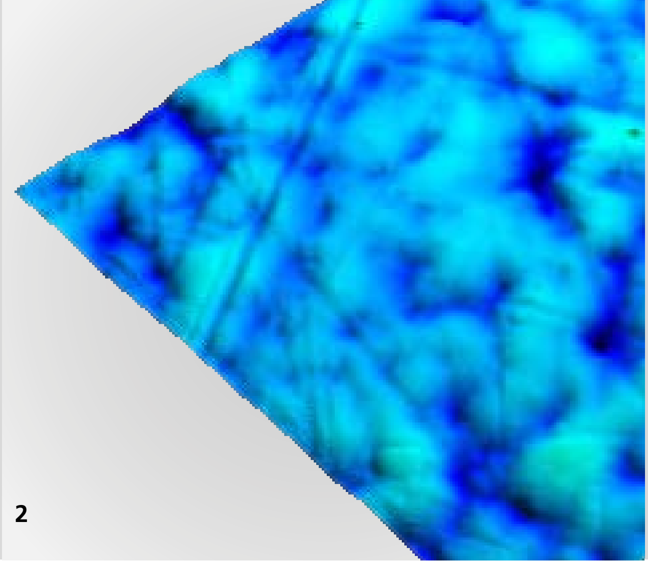

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LUBRICANT-FREE COLD FORMING OF ALUMINUM SHEETS

Aluminum alloys are utilized in numerous fields of application on account of the favorable weight-strength ratio, whereby the cold forming of sheet metal semi-finished products is the most common application. Due to the strong adhesion tendency of aluminum, lubricants must currently be used in order to achieve a sufficiently long tool life and high component quality. This does not only result in an increase in working material and disposal costs but also often requires laborious procedures for the subsequent lubricant removal. An approach for the economically and ecologically more efficient configuration of the production process is provided in the form of a tool coating on the basis of amorphous hydrocarbon (a-C:H), developed at the Fraunhofer IST.

Current tool coatings

For the coating of tools for the cold forming of aluminum sheets, a wide variety of hard thin films have been established. As lubricants are currently applied in order to reduce adhesion, these tool coatings are not only optimized with regard to high resistance to abrasive wear but also with respect to bonding and interaction with the additives contained in the lubricant. At present, there is a development trend towards reducing the lubricant consumption. There are, however, no established industrial tool coatings which could enable a complete renouncement of lubricants. With the current technological status, even layers of diamond-like carbon (DLC) cannot completely prevent adhesive tool wear.

Layer development

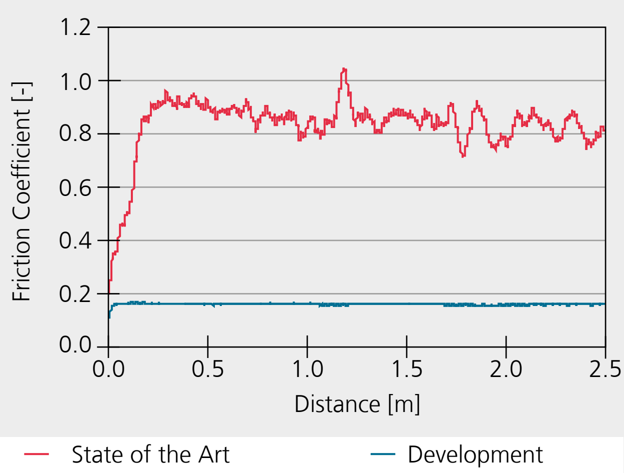
Within the framework of the Priority Program SPP 1676 from the Deutsche Forschungsgemeinschaft (German Research Foundation, DFG), the Fraunhofer IST carries out further development of amorphous hydrocarbon layers (a-C:H) with the realization of lubricant-free aluminum forming as its objective. Over the course of the latest developments, it was possible to verify that the nanoscopic surface roughness is a significant influencing factor on the adhesion tendency of a-C:H layers. Adhesive layer wear can be prevented and low friction (see Figure 2) can be achieved in the lubricant-free contact with aluminum through a reduction in the nanoscopic surface roughness as shown in Figure 1. For the deposition of correspondingly smooth a-C:H coating systems, various strategies for action, consisting of an optimized coating process and a subsequent surface treatment, were developed and qualified for actual application.

Transfer of results to industrial forming processes

The roughness requirements represent another optimization variable in addition to the coating properties which have formed the focus of attention so far, e. g. hardness, wear resistance, adhesion, etc. Furthermore, the surface quality of the forming tool plays an important role in the transfer of development results to real forming processes. In order to fulfill these requirements, a holistic optimization of the layer-tool bond is necessary. The selection of the tool material, the manufacture of the tool, the actual coating process and the post-treatment of the a-C:H tool coating must thereby

be included. The Fraunhofer IST has acquired many years of experience in comprehensive tool optimization with numerous industrial partners. As a result, it has already been possible to demonstrate the lubricant-free deep-drawing of high-alloy aluminum sheets in initial application tests (see Figure 3).

Friction coefficient curve for the developed a-C:H layers in lubricant-free friction contact with aluminum EN AW-5083.



Outlook

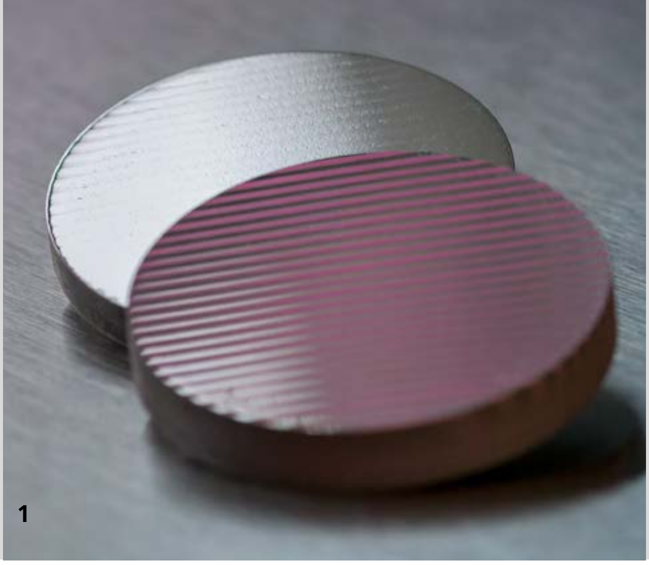
The Fraunhofer IST plans to implement the described results in the industrial manufacture of aluminum components.

1,2 *AFM images of an a-C:H layer in accordance with the current technological status (left) and the developed a-C:H layer (right).*

3,4 *Photo overview of a-C:H-coated cup drawing tools following lubricant-free application tests with aluminum sheets made from EN AW-5083: Adhesion formation on an a-C:H layer in accordance with the current technological status (left) and the developed a-C:H layer (right).*

CONTACT

Dipl. Wirt.-Ing. Tim Abraham
Phone +49 531 2155-655
tim.abraham@ist.fraunhofer.de



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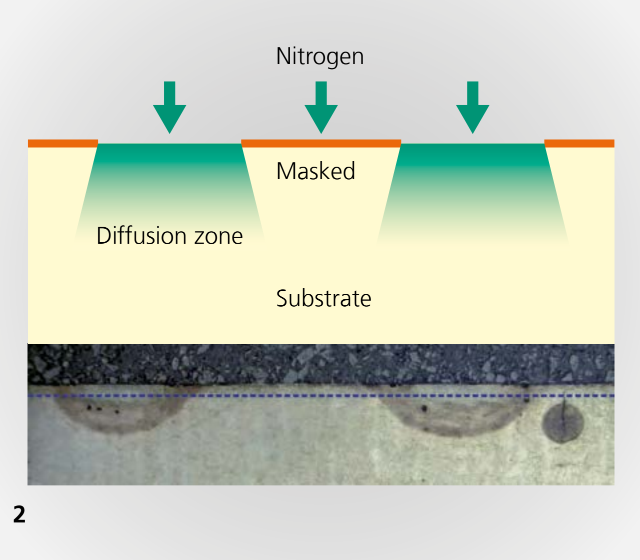

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THERMAL SHOCK RESISTANT TOOL SURFACES

Forging presents an effective production method for the manufacture of safety-relevant components with outstanding mechanical properties. Their economic efficiency depends directly on tool wear during production which limits the service life of relevant components. Wear is primarily caused by complex interacting mechanical and thermal loads. At the Fraunhofer IST, a number of approaches concerning the improvement of nitriding processes aim at the minimization of wear in different production environments. Particular attention is, thereby, paid to the optimization of tool surfaces which are strained by thermally alternating stress, the so-called thermal shock.

Tool wear through local treatments

The thermal overheating generated through direct contact between the workpiece and the tool during the forming process can cause both a plastic deformation and pronounced abrasive wear.

Through modification of the tool surface and edge zone, e.g. by means of nitriding, it is possible to avoid the thermal softening. The intensive nitriding of surfaces can, however, lead to increased sensitivity for cracking and, therefore, the facilitation of flaking of the material on the treated surface. Current project results, which have already been evaluated in industrial forging applications such as the production of turbine blades or gear wheels, demonstrate the high technological potential of adapted local treatments: By covering specific areas with pastes preventing nitrogen diffusion significant service-life advantages can be achieved.

New approaches for the prevention of crack formation in tool surfaces

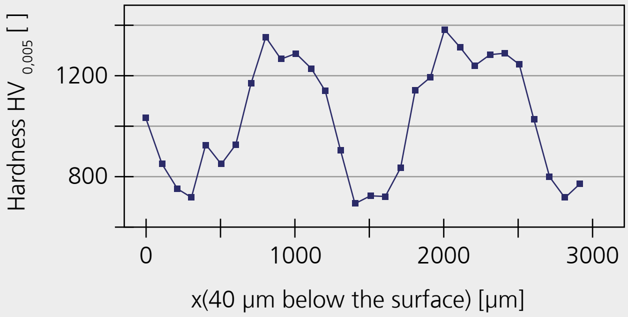
Pastes are used in order to structure material areas in the edge layer zone with adaptable patterns in such a way that ductile zones are created next to nitrided zones (see Figure 1). This way, the formation and propagation of cracks under thermal shock conditions can be prevented. The selection of suitable designs is, however, subject to certain geometric requirements. In addition, industrial suitability must also be taken into account in regards to an automatable, easily reproducible pattern transfer.

Other ways for reducing crack formation under thermal shock conditions result from process combinations of differing diffusion treatments with nitrogen (plasma nitriding, PN) or nitrogen and carbon (plasma nitrocarburizing, PNC) as well as subsequent heat treatments. The latter can be integrated into the vacuum treatment process. However, subsequent treatments performed close to the surface, such as laser-beam treatment or inductive heating, also show promising results regarding a crack-resistant surface.

New possibilities in analytical characterization methods for testing the crack sensitivity of surface zone layers, such as the implementation of the scratch test to evaluate the ductility of the edge zones, have confirmed the developed treatment concepts.

1 *Structured sample.*

2 *Concept of so-called "expansion joint nitriding" with cross section.*



Hardness measurements taken 40 µm below the structured surface demonstrate the effects of the covering: Whilst ductile zones form under the covered and thereby untreated areas, nitrided zones form under free areas with a high hardness.

Evaluation

For the evaluation of the development at laboratory level, a system of test benches is used which represents the production-related thermal shock conditions as realistically as possible. Furthermore, serial forging tests with adapted test geometries for differently exposed die areas and tests in the field of industrial manufacturing demonstrate a high potential for commercial implementation.

Industrial benefits

In addition to the stabilization of the service life and the reduction of specific wear mechanisms through thermal influences, the crack behavior is positively influenced. This leads to a higher efficiency of the industrial production process and enables a more economic production during the forging campaigns of industrial partners.

CONTACT

Dipl.-Ing. Hanno Paschke
Phone +49 231 844-5453
hanno.paschke@ist.fraunhofer.de

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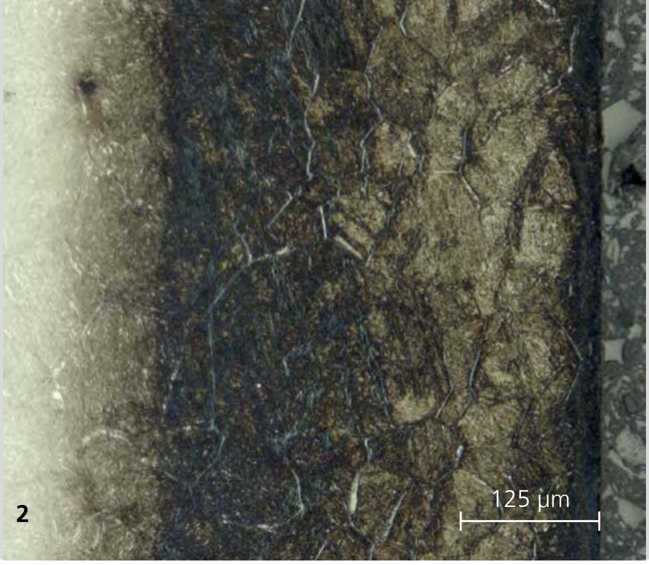

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PREDICTION OF PLASMA NITRIDING RESULTS

Plasma nitriding is an established process for the surface-hardening of steels and is implemented for a multitude of tools and components. The nitriding result, thereby, depends considerably on the utilized steel materials and the process parameters. Knowledge concerning the process control is largely based on empirical values with frequently used materials. In order to select an ideal plasma nitriding process for new materials and applications, elaborate preliminary tests are generally necessary. At Fraunhofer IST, a prediction tool has therefore been developed forecasting the results of plasma nitriding processes, thereby, enabling an improvement in the quality of treated components.

New possibilities for end users

Users of plasma nitriding technology are often faced with the decision as to which specifications should be made for an optimum nitriding result and which process parameters must be set for this purpose. Generally, the specifications are limited to an indication of the desired nitriding hardness depth, and standard processes for the nitriding are implemented which are not optimally coordinated with the material, the geometry or the end application. The potential of plasma nitriding technology is therefore often not fully exploited. In this respect, the new software-based prediction tool from Fraunhofer IST offers users extensive possibilities regarding improving the quality of the components.

Factors influencing the nitriding result

Complex relationships exist between the nitriding parameters, such as treatment duration, process temperature and gas composition, the alloying elements contained in the base material the component geometry and the nitriding result. The most important characteristic values are:

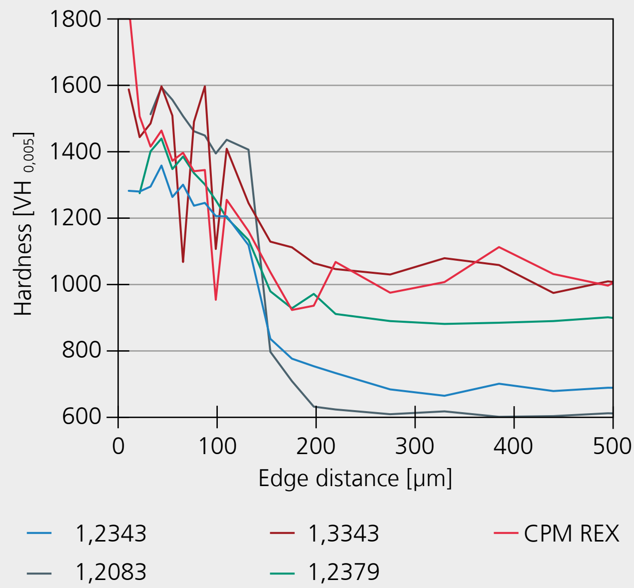
- The nitriding hardness depth and the hardness gradient in the material, which can be taken from the determined hardness depth profiles (see Figure 2 and adjacent diagram).
- The compound layer formed on the surface of the material, which can vary both in its chemical composition (Fe_4N, $Fe_{2-3}N$) and thickness. An almost complete suppression is also possible
- The crack sensitivity of the nitrided surface under load can, for example, be determined analogously to the Rockwell penetration test in accordance with DIN 4856:2018-02. For this purpose, a separate evaluation scheme for nitrided surfaces has already been developed in earlier work.

Data collection through sample evaluation

In the past, secure knowledge was lacking regarding the relationships between the nitriding parameters, the base materials and the nitriding result as well as the necessary database. Within the framework of the IGF project “Prognosetool für Plasmanitrierprozesse zur Randschichtbehandlung von Werkzeugen und Bauteilen” (Prediction tool for plasma nitriding processes for the surface treatment of tools and components, ProgPlas), more than 500 combinations of widely differing materials and process parameters were investigated. Subsequently, the treated samples were comprehensively evaluated. For validation of the results, comparative tests were performed on industrial facilities. Simultaneously, in cooperation with the Institute of Materials Science and Engineering (IWW) at the Chemnitz University of Technology, a neural network was trained using the data, which provides the basis for the development of a software-based prediction tool for plasma nitriding processes.

1 *Components during plasma nitriding treatment.*

2 *Microstructure of a nitrided surface zone.*



The resulting hardness depth profile dependent on the material.

Benefits for the user

The results of the investigations were compiled in the form of a user-friendly data collection, which makes it possible to estimate the nitriding result, e. g. for given material and process parameters or, alternatively, to specifically select the required process parameters for the desired nitriding result. Due to the comprehensive database, the potential of plasma nitriding technology can be utilized in the best possible way. Through the optimized approaches, both the tool life and the service life of components can be extended considerably.

The project

The industrial joint research project IGF 18741 BG was funded by the German federal Ministry for Economic Affairs and Energy on the basis of a resolution of the German Bundestag, with support from the research association "Deutsche Gesellschaft für Galvano- und Oberflächentechnik e.V." (German society for galvanic and surface technology).

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CONTACT

M.Sc. Markus Mejauschek
Phone +49 531 2155-679
markus.mejauschek@ist.fraunhofer.de

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PLASMA REPLACES ADHESIVE – NOW ALSO AS ROLL-TO-ROLL

The utilization of new materials is an essential foundation for the innovations of the 21st century and the basis for modern products in all areas of life. The demand for composite films, e. g. for food packaging, flexible circuit board or decorative and protective films, is increasing continuously. Therefore, the Fraunhofer IST is working together with project partners on a solution for the scaling-up of a new inline-capable joining process for the production of such composite materials from metal and plastic films.

Scaling-up to the roll-to-roll procedure

Within two successfully completed IGF projects of the German Federation of Industrial Research Associations (AiF) in collaboration with the Forschungsinstitut Leder und Kunststoffbahnen (Research Institute of Leather and Plastic Sheeting, FILK) in Freiberg, a process for the lamination of plastic/plastic and metal/plastic composites through surface functionalization by means of atmospheric pressure plasmas has been developed. The functionalization is based on an oxygen-free plasma treatment using precursors.

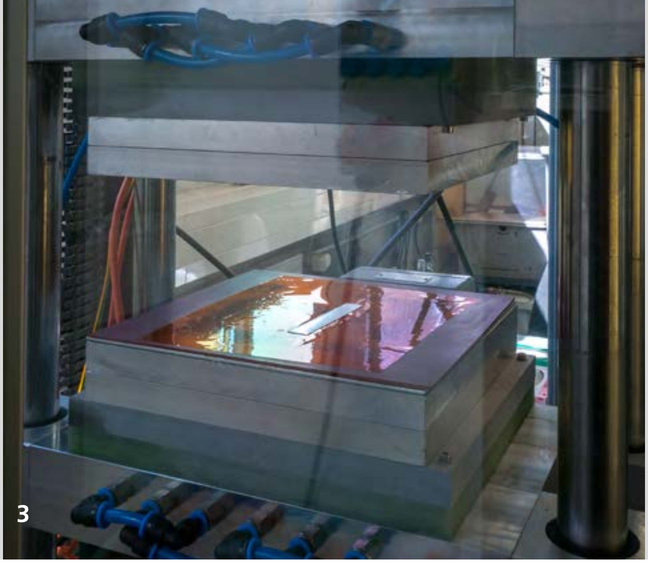
Directly after the joining surfaces have been equipped with chemically reactive groups, the lamination takes place considerably below the melting temperature, e. g. at 60 °C. The process is currently being scaled-up as an inline process, thereby further reducing the time between functionalization and lamination. This enables the integration of this procedure into existing inline processes. The substrate speed can be adjusted through the design of the plasma path and the roll or belt laminator. In order to adjust the plasma functionalization to the lamination in continuous operation, the surface functionalization is optimized. This applies to both the density of the reactive groups across the treatment width and the uniformity over a continuous coating time of eight hours.

State of the art

The aforementioned composites still have to be partially activated wet-chemically and joined using diverse adhesives today. These are usually solvent and water-based adhesives, UV adhesives or adhesive films. Ultimately, the adhesive strength between the material components should be at least high enough for adhesion breaks to stop. Simultaneously, the requirements placed upon composites are increasing in terms of material usage, long-term durability and creep tendency or migration. These requirements are often economically unattainable with adhesive joints. The thermal adhesive-free lamination can, however, only be applied between compatible material pairings. The material properties, such as optical quality or haptics, often suffer as a result of the melting of a joining partner.

Outlook

Restrictions which have, until now, stood in the way of an industrial application of the plasma process for joining are the challenges with regard to the quality assurance of the surface functionalization as well as electrode contamination during longer process times. In order to establish an understanding of the correlation between layer thickness and adhesive force, investigations are carried out by means of ellipsometry. This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makes it possible to precisely determine even nanometer-thick layers on foils. Furthermore, infrared spectroscopy can be implemented in order to acquire knowledge concerning physical and chemical processes and the associated surface changes. The characterization of the precursor concentration in the process gas is performed by means of mass spectrometry. One objective of the investigations is the scaling-up of low-temperature joining for industrial applications, thereby providing small and medium-sized enterprises with better access to this technology.

The project

Project 19571 N of the research association "Verein zur Förderung des Institutes Leder und Kunststoffbahnen Freiberg/Sachsen e.V. FILK" was funded by the German Federal Ministry for Economic Affairs and Energy via the AiF within the framework of the program for the promotion of joint industrial research (IGF) on the basis of a resolution of the German Bundestag.

1 *Aldyne™ plant for continuous roll-to-roll coating.*

2 *90° pull-of tester for foil composites.*

3 *Thermo-compression bonder for plasma pretreated film components.*

CONTACT

Dr.-Ing. Marko Eichler
Phone +49 531 2155-636
marko.eichler@ist.fraunhofer.de


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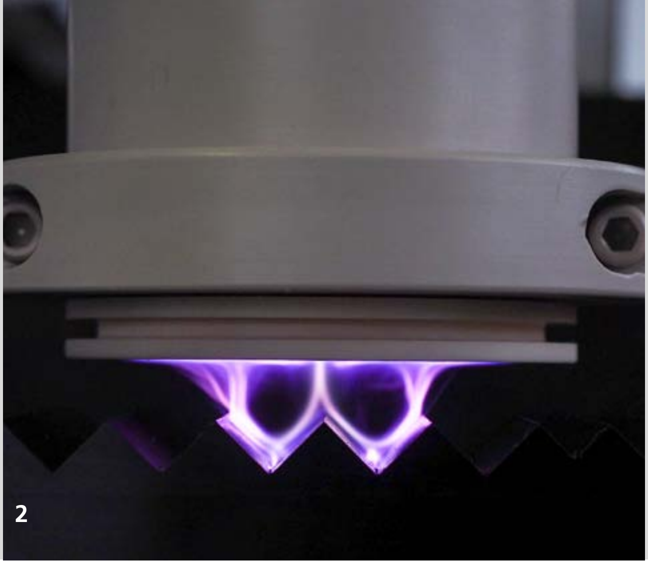
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COMPACT JET-INDUCED SLIDING DISCHARGE SOURCE

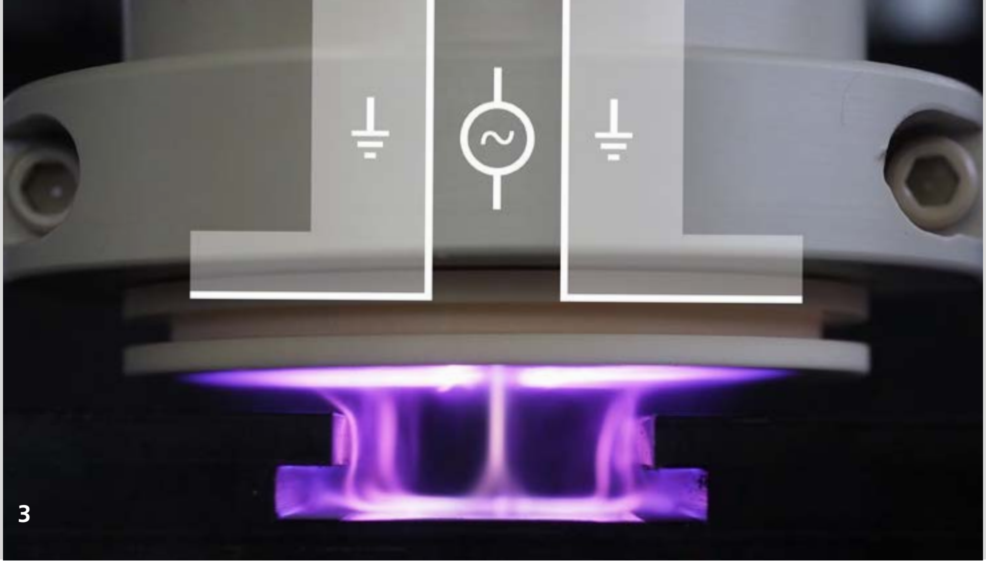
Commercially available atmospheric-pressure plasma sources are today already being utilized in the most diverse sectors and areas of industry for the cleaning and activation of surfaces. Through the application of plasma processes, it is possible for e. g. paints and adhesives to adhere to surfaces without chemical pre-treatment. This saves costs and is environmentally friendly. Depending on the field of application, effective solutions for the activation, functionalization, ultra-fine cleaning or coating of surfaces are available, ranging thereby from laminar pre-treatments such as corona activation for sheet goods to the partial treatment of three-dimensional components with plasma jets. The plasma treatment of laminar and simultaneously partially complex geometries, such as deep-set slots, cavities or undercuts does, however, pose a particular challenge. Costly array arrangements with plasma jets or complicated combination solutions are often unavoidable here. At the Fraunhofer IST, a plasma source concept based on a jet-induced sliding discharge has been developed which enables the effective activation or functionalization of even geometrically challenging contours.

The functional principle

Inside the sliding discharge source, a cold plasma on the basis of a dielectric barrier discharge (DBE) is initially ignited by means of alternating voltage. As shown in Figure 3, this is driven out of the center of the nozzle by the process gas flow and strikes the substrate surface. Here, sliding discharges in the form of long plasma filaments develop towards the earth electrode on the underside of the plasma source. These plasma filaments affect the substrate surface along its contour. This process enables a uniform and comprehensive treatment of surfaces, including possible indentations or cavities. Depending on the source execution and the distance from the source to the substrate (1 – 40 mm), effective treatment widths of between 10 and 120 mm are available.

A very good alternative to wet chemistry

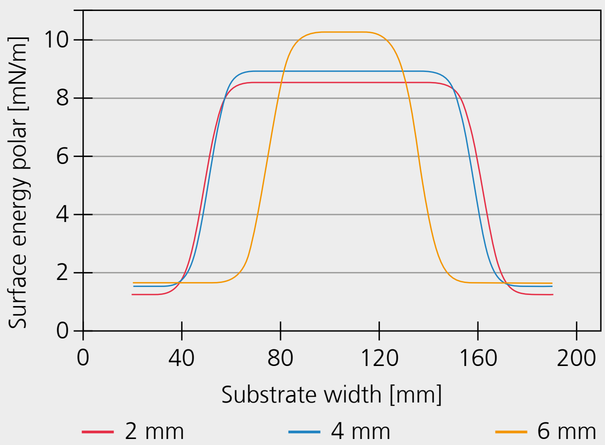
The plasma source concept was developed within the framework of a publicly funded project as an alternative for wet-chemical primers in the preliminary stages of painting and laminating processes on PVC extrusion semi-finished products. As the ambient air in the treatment area is virtually completely displaced, the jet geometry furthermore ensures very homogeneous and reproducible treatment effects – largely independent of the prevailing ambient conditions – and enables, depending on the discharge distance, the utilized process gas and the specific plasma parameters, a very precise adaptation of the surface energy of the substrate to the medium which is to be applied, e. g. paint or adhesive system. Very efficient results have been achieved on PVC as well as on all other common polymer materials.



1 *Laminar sliding discharge under exclusion of ambient air in a defined process environment.*

2 *Surface treatment of a gear rack.*

3 *Discharge characteristics and functional principle of the sliding discharge plasma jet during the surface treatment of a T-slot.*



Effective discharge widths of the plasma jet determined by the change in the polarity of the surface in dependence on the substrate distance.

Outlook

In close collaboration with industrial partners, the plasma source concept developed at the Fraunhofer IST is to be transposed into a practicable commercial solution in the future in order to provide a decisive contribution towards sustainable and environmentally friendly production processes.

The project

The described results were achieved within the project "Neuartiges Plasmakonzept zur Oberflächenfunktionalisierung von Polymer-Extrusionshalbzeugen bei Atmosphärendruck unter Vermeidung von gesundheitsgefährdenden Stoffen – KF 2004825DF4" (Innovative plasma concept for the surface functionalization of polymer-extrusion semi-finished products at atmospheric pressure under the avoidance of hazardous substances - KF 2004825DF4), which was funded by the German Federal Ministry for Economic Affairs and Energy (BMWi).
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CONTACT

Martin Bellmann
Phone +49 551 3705-379
martin.bellmann@ist.fraunhofer.de

AEROSPACE

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

Currently the Fraunhofer IST is working on the following projects:

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

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

Additive Manufacturing: Galvanic deposition on filigree 3D printed structures.


1


2

STRUCTURES FOR AIRFLOW INVESTIGATIONS

In space travel, re-entry bodies are built with thermal shields to protect them against the enormous heat when entering the atmosphere. These shields must fulfill high safety standards. In order to be able to dimension them correctly, the influence of their surface properties on transition from laminar to turbulent flow is being measured in wind-tunnel investigations at the Institute of Fluid Mechanics of the Technische Universität Braunschweig. Within the framework of the project "HYPTRANS PAK742", the Fraunhofer Institute for Surface Engineering and Thin Films IST has therefore produced microstructures of differing roughness on a generic Apollo capsule.

Microstructures with defined roughness

A UV-sensitive photoresist, as used in semiconductor technology, is applied to the surface of the wind tunnel capsule model. Subsequently, a tempering step is performed. An exposure mask is then applied and exposed to UV radiation. Following development, resist microstructures remain on the surface in the center of the capsule base body (see Figure 2). The quadratic structures have a height of 20 µm and an edge length of 100 µm. The microscope image in Figure 3 shows that the distance between two microstructures is 100 µm as well. The entire so-called roughness patch covers an area of 20x20 mm².

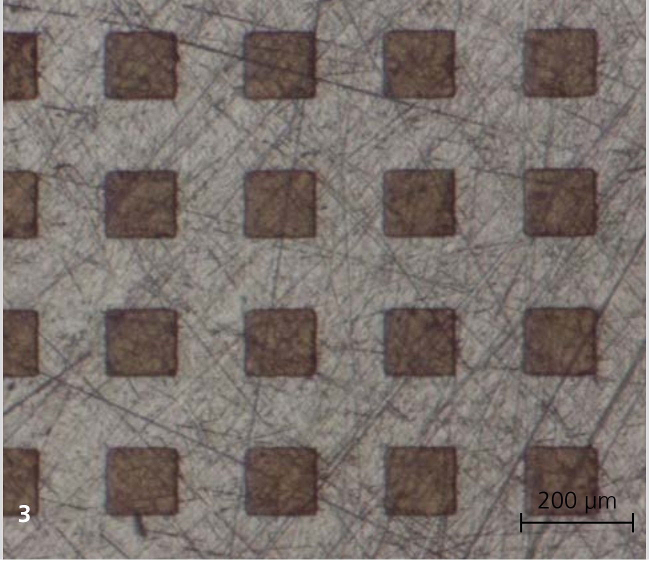
Wind-tunnel trials

For the investigation of the transition processes, heatflux sensors are flush-mounted on the surface of the produced roughness patch. In order to be able to unequivocally determine whether the measured heat flows are in the laminar or turbulent range, simulation data are available for comparison with regard to the laminar heatflux distribution. A deviation of more than 5 percent from the laminar calculation is considered to be the starting point of the transition.

The simulated heat flow is derived from a purely laminar flow simulation with an ideally smooth wall. This dataset allows, through comparison, the categorization of the experimental data with respect to the shift from laminar flow to transition. It can be seen that, compared with the ideally smooth measurement configuration, the subcritical roughness patch has no influence and that a transition in the vicinity of the capsule shoulder only occurs once the freestream tunnel noise becomes sufficiently high, which corresponds to an alteration of the capsule position in the test area.

Outlook

For the next phase of experiments, the height of the elements will be set to 80 µm in order to obtain access to the area of pure roughness-based transition. The spaces between the structures are dimensioned with an optimal wavelength which, according to the flow simulation, predicts an optimal increase of disturbance energy causing transition.



1 Illustration of an Apollo capsule re-entering the atmosphere.

2 Test capsule with microstructures.

3 Microscope image of the microstructures on the surface of the test capsule.

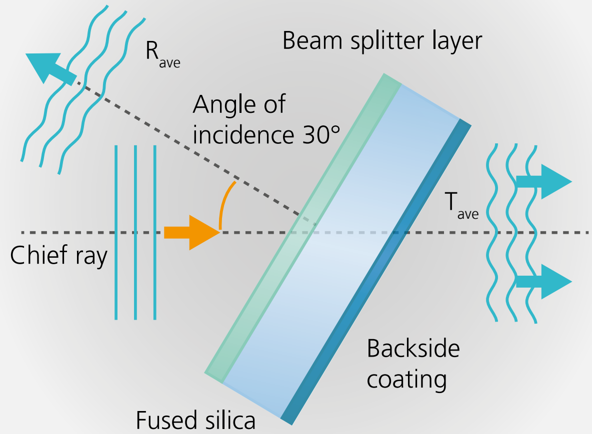
The project

The described results were obtained within the project "HYPTRANS PAK742". The project was funded by the Deutsche Forschungsgemeinschaft (German organization for science and research, DFG) within the second funding period from 2015 to 2018.

CONTACT

Dr. Saskia Biehl
Phone +49 531 2155-604
saskia.biehl@ist.fraunhofer.de

Nancy Paetsch
Phone +49 531 2155-765
nancy.paetsch@ist.fraunhofer.de



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BROADBAND BEAM SPLITTER WITH LOW WAVEFRONT ERROR

In many optical instruments so-called beam splitters are utilized. These are often used to separate individual spectral ranges in order to guide the light to the various spectrometers. With very high-quality instruments the wavefront error must be extremely small in order to minimize aberrations. Within the framework of a European Space Agency (ESA) project, the Fraunhofer IST has developed such a broadband beam splitter with very low wavefront error (20 nm rms).

The aim: coating of broadband beam splitters

The aim of the project was to develop a beam splitter with a diameter of 120 mm which exhibits a high reflection of more than 98 percent in the spectral range of 400 to 900 nm at an angle of incidence of 30° and, simultaneously, a transmission of more than 92 percent in the NIR range of 920 to 2300 nm. In order to achieve this, a very high-quality optical coating was developed consisting of a dielectric layer stack, which was deposited with the help of the EOSS® (Enhanced Optical Sputtering System) sputtering facility.

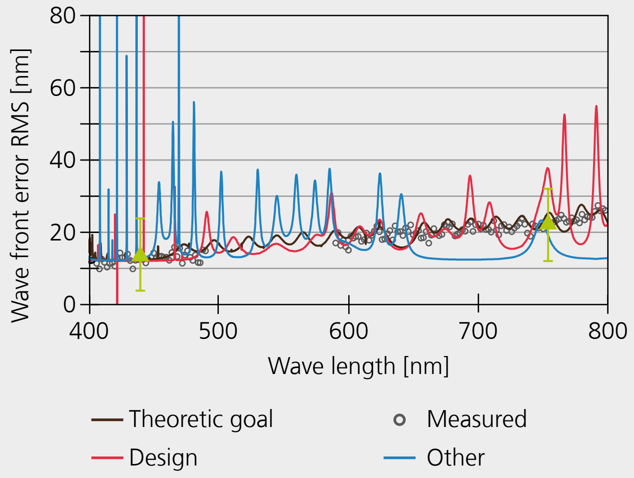
Minimization of wavefront errors

Wavefront defects in optical coatings can have a number of causes. In order to minimize this error, a very high-quality substrate with a root mean square (RMS) error of 2 nm must first be utilized. A further source of errors are layer tensions, which can lead to bending of the substrate. Even for a substrate with a thickness of 12 mm, a non-compensated coating would lead to a distortion of more than 2 µm with a corresponding wavefront error. In the present case, an excellent compensation of coating stress could be achieved through a double-sided coating. Under certain circumstances, very large resonance-like wavefront errors can occur at certain wavelengths, which exceed the specifications many times over. In order to provide a solution for this situation, a completely new layer design was developed which is characterized by a very low wavefront error.

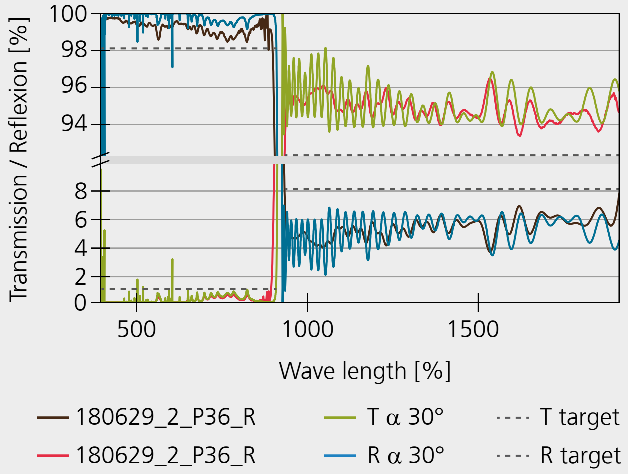
Production of the coating using the EOSS® facility

For the coating of the beam splitter, the EOSS® was utilized, with which high-precision optical interference filter systems can be produced. The total system consists of 150 layers and is 14.4 µm thick on both sides of the component. Through the optimization of the process, it was possible to significantly reduce the losses of the beam splitter. The deposition of the filter had to be performed with the highest precision as, due to the polarization splitting, a widening of the edge occurs for s- and p-polarized light. The layer design was created with a tolerance safety of less than 1 nm. In order to realize the smallest possible wavefront error, the deviation of the layer thickness distribution was reduced to a value of less than +/- 0.125 percent–worldwide a peak value.

1 *Scheme of the beam splitter and its geometry.*



Calculated and measured transmission and reflection of the beam splitter. The deviations in the NIR range result from the spectral resolution of the spectrometer.

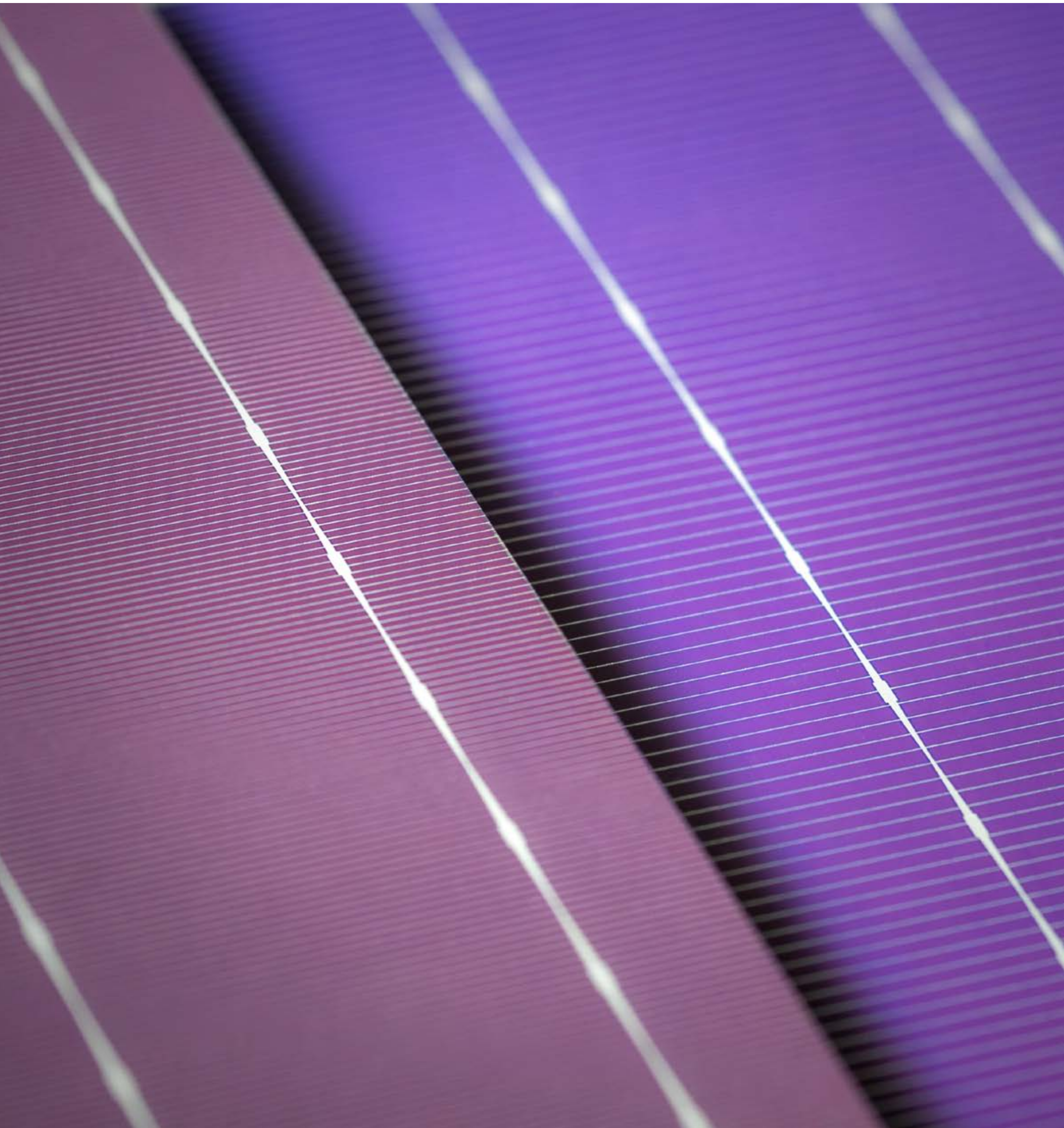


High-resolution measurement of the transmission at an angle of 30° (s- and p-polarization) in the edge area.

CONTACT

Dr. Michael Vergöhl
Phone +49 531 2155-640
michael.vergoehl@ist.fraunhofer.de

ENERGY AND ELECTRONICS



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

- Functional coatings or coating systems and coating processes for architectural glass (low-E-coatings, active or passive heat and sun protection, switchable electrochromic glazing)

- Transparent conductive coating systems (TCOs) for architectural and automotive glazing, for solar cells, displays and invisible heating elements and also for solar thermal energy

- p- and n-type TCOs as materials for transparent and flexible electronics

- Semiconductor layers for thin-film and silicon-based photovoltaics and also characterization methods for thin-film solar cells

- Electrical contact and insulating layers, as well as barrier layers

- (Local) plasma treatment of surfaces for wafer bonding, structured metallization and metallization of temperature-sensitive and complexly shaped substrates

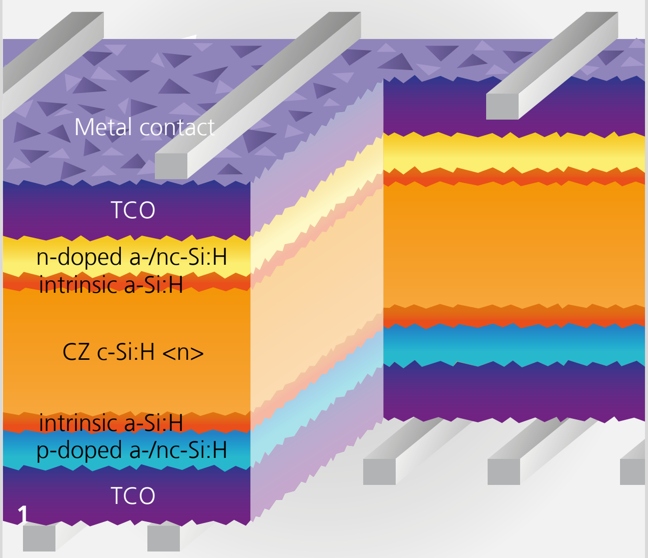
- Stable anodes and cathodes for lithium-ion batteries

- Electrolytic coatings for high-temperature fuel cells (SOFC) and gas separation membranes for hydrogen production

- Corrosion-protection and thermal-barrier coatings for high-temperature applications, such as in gas turbines

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

Silicon layers produced by HWCVD for a heterostructure solar cell.



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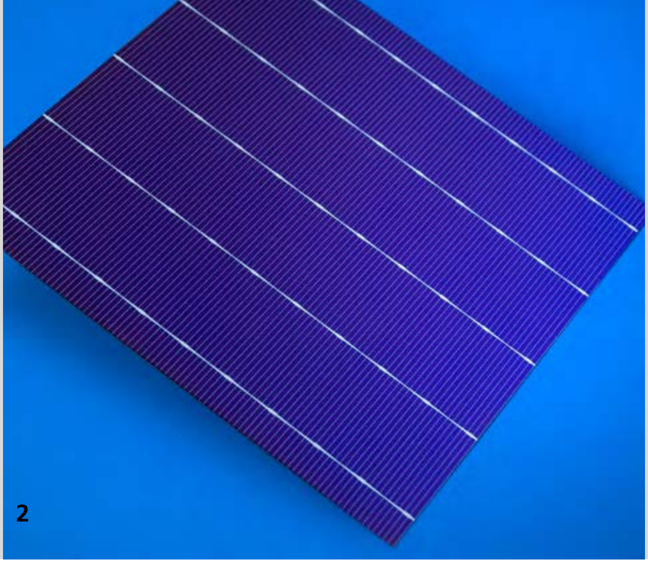
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SILICON LAYERS FOR HETEROSTRUCTURE SOLAR CELLS

For decades, silicon has been used as a semiconductor and is therefore an important component in the photovoltaic industry. Among the solar cells based on crystalline silicon (c-Si), silicon heterostructure solar cells (silicon heterojunction, SHJ) distinguish themselves through their particularly high efficiency rates of more than 26 percent. Hot-wire chemical vapor deposition (HWCVD) presents a promising technology for the cost-effective deposition of low-defect silicon layers. For this reason, the Fraunhofer IST is utilizing the process in order to investigate its suitability for the manufacture of highly efficient SHJ solar cells, in particular for applications within the automotive sector.

The structure of SHJ solar cells

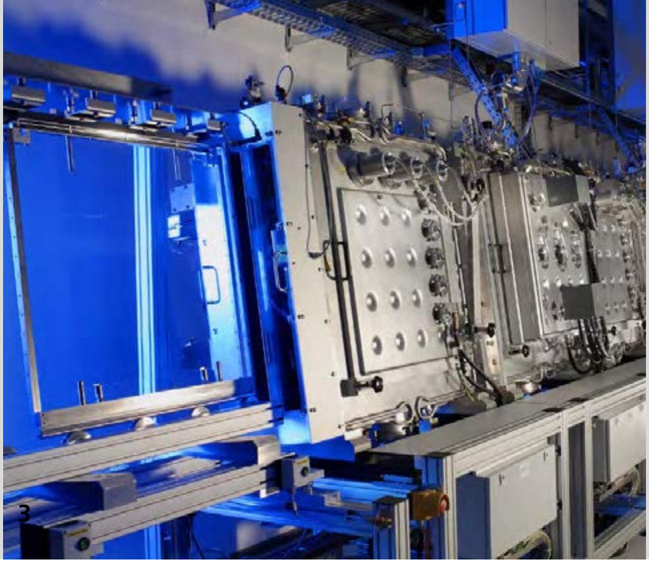
In SHJ solar cells, crystalline Si wafers serve as absorbers in which sunlight is converted into free charge carriers. Decisive for the achievement of high efficiency rates in these solar cells is that the charge carriers, during their passage to the contacts, do not recombine at defects on the wafer surfaces which act as recombination centers. For the saturation of surface defects, extremely thin passivation layers made from amorphous silicon (a-Si:H) are applied to both sides of the wafer, followed by the p- or n-doped Si layers, a transparent conductive oxide layer (TCO) and, finally, the metallic contacts (see Figure 1).

Advantages of hot-wire-activated gas-phase deposition

Within the framework of a project funded by the BMWi, the HWCVD process is used instead of the plasma-enhanced chemical vapor deposition (PECVD) for the production of intrinsic and doped silicon layers. With HWCVD, the process gas mixtures are activated by resistively heated metal wires. The layer formation takes place exclusively through radicals formed thereby in complete absence of high-energy particles. As HWCVD deposition therefore takes place without particle bombardment, the process is particularly suitable for the gentle production of low-defect coatings, which are expected to exhibit exceptionally good passivation properties. A further advantage is that through HWCVD processes, it was possible to achieve a high process gas exploitation of more than 80 percent and, therefore, also higher deposition rates of more than 2 nm/s. This results in considerable cost advantages compared to PECVD processes.

Deposition of silicon layer stacks

The silicon layers were deposited in a large-area HWCVD inline coating system developed by the Fraunhofer IST (see Figure 2), which has three coating chambers with areas of up to 500 x 600 mm². As shown in Figure 3, four solar wafers with a format of 156 x 156 mm² can be coated simultaneously. The process conditions were optimized for layer thicknesses of 10 to 20 nm. On textured wafers, charge carrier lifetimes of up to 5 ms were achieved. As the basis for the production of SHJ cells, passivation layers with a thickness of 6 nm and carrier lifetimes of around 1 ms were first utilized. The production of the n- and p-doped silicon layers was carried out through the addition of the doping gases phosphine (PH_3) and diborane (B_2H_6). The conductivity of the doped layers was pre-optimized



through the addition of hydrogen (H_2), whereby the layers became nanocrystalline.

Results

The stacks of intrinsic a-Si:H passivation layers produced at the Fraunhofer IST from pure SiH_4 gas and doped layers with differing conductivities and layer thicknesses were further processed by the project partners to form complete solar cells, and the component properties were investigated by means of their current-voltage characteristic curves. With the layer stacks tested to date, cell efficiency rates of 19.4 percent have already been achieved. Through further optimization of the layer system, the efficiency rates should be significantly improved by the end of the project.

The project

The work presented here was carried out within the framework of the project "Prozess- und Anlagentechnologie zur kostengünstigen und ressourcenschonenden Herstellung von Silizium-Heterostruktursolarzellen mit hohem Wirkungsgrad" (process and plant technology for the cost-effective and resource-saving manufacture of silicon heterostructure solar cells with high efficiency rates, "PATOS"), which is funded by the German Federal Ministry for Economic Affairs and Energy (BMWi) and which will run from 1st September 2016 to 31st August 2019.

We would like to thank the project partners RENA Technologies GmbH, Forschungszentrum Jülich, VON ARDENNE GmbH, IHT Aachen, edgeWave GmbH, a2-solar GmbH, and AUDI.

1 Basic structure of an SHJ solar cell.

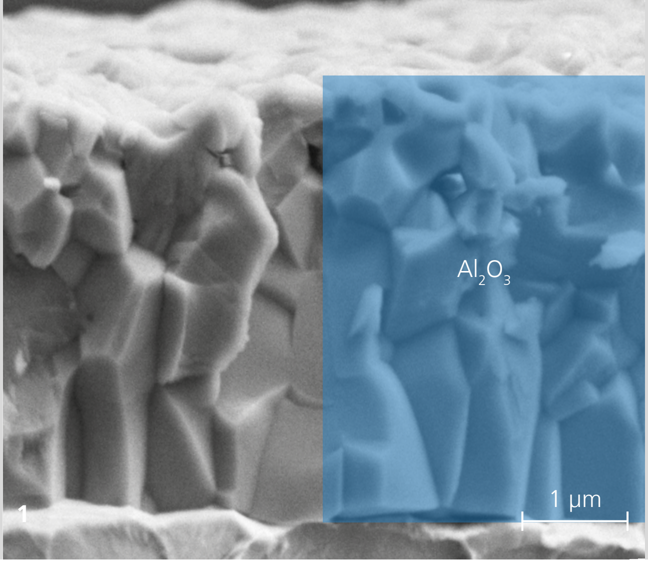
2 Silicon layers produced by HWCVD for a heterostructure solar cell.

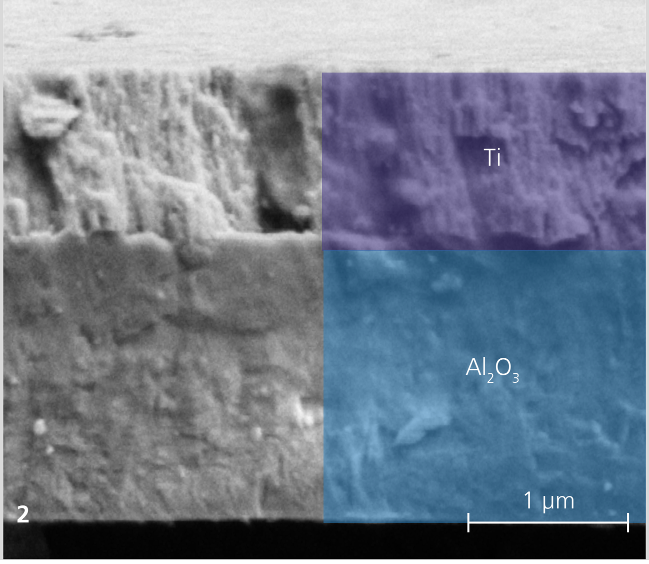
3 HWCVD inline coating system at the Fraunhofer IST.

CONTACT

Madeleine Justianto, M.Sc.
Phone +49 531 2155-523
madeleine.justianto@ist.fraunhofer.de

Dr. Volker Sittinger
Phone +49 531 2155-512
volker.sittinger@ist.fraunhofer.de





OXIDE LAYERS FOR HIGH TEMPERATURES

In high-temperature combustion processes such as gas-fired or aircraft engines, metal surfaces are subjected to extreme temperatures. Oxide layers produced and tested at the Fraunhofer IST can effectively protect metal materials against destruction through hot gas corrosion. In the combustion chambers of e. g. gas turbines these significantly determine the service life of the components. Furthermore, oxide based electrical insulation layers enable the utilization of sensorial functional layers on components. Particularly in high temperature environments (>1000 °C), the task of oxide layers is especially demanding.

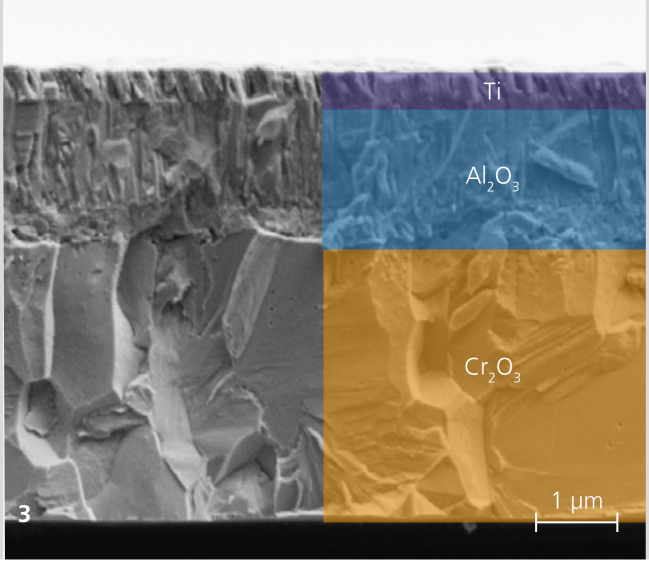
Oxide layers for high and highest temperatures

Metal materials which, due to their application, are exposed to very high temperatures require a protective surface layer. Generally, chromium or aluminum is used for this. The layers of pure chromium oxide (Cr_2O_3) or pure aluminum oxide (Al_2O_3) formed at high temperatures must adhere well, be dense and free of cracks, grow sufficiently slowly and not evaporate significantly. At temperatures above 1000 °C, practically solely the thermodynamically stable high-temperature phase of aluminum oxide (α-Al_2O_3, corundum) fulfils these conditions.

The stable phase of the aluminum oxide can be produced thermally from suitable oxide formers such as MCrAlY. The growth of aluminum oxide takes place from the outside to the inside through the diffusion of oxygen ions to the interface with the metal. The addition of alloying elements, such as yttrium, to the oxide formers improves the adhesion and the service life of such protective coatings. Figure 1 shows a thermally grown aluminum oxide which has formed on an FeCrAl alloy at 1050 °C.

Sputtered aluminum oxide layers

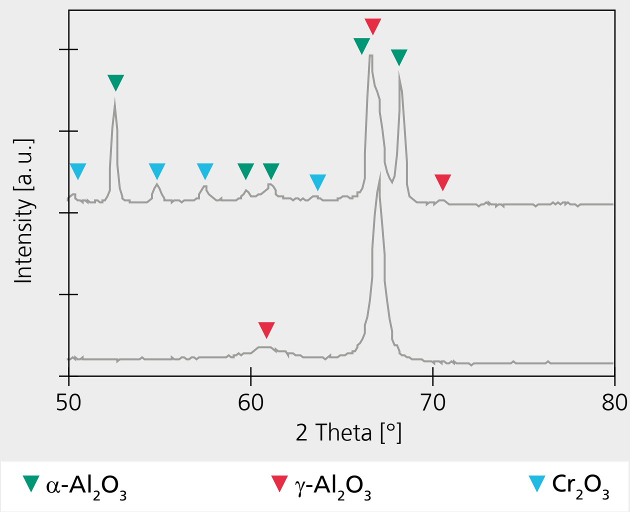
Well-adhering protective layers of pure aluminum oxide can also be applied to heated metallic components by means of thin film techniques, e. g. reactive gas flow sputtering (see Figures 2 and 3). The decisive factor hereby is that, if possible, the α-phase is already present in the layer prior to the first application at high temperatures. A heating of the low temperature phase (γ-Al_2O_3) above the threshold of 1000 °C would lead to a strong alteration in volume due to the phase transformation and therefore to the failure of the layer compound. Furthermore, pores can form within the layer which then impair the application. Tests at the Fraunhofer IST have shown that by means of ion assistance or suitable template layers, the formation of the α-phase is already promoted at deposition temperatures of approx. 830 °C. By means of X-ray diffractograms of reactive sputtered aluminum oxide layers, Figure 3 shows that a chromium template layer encourages the development of the rhombohedral corundum phase.



1 *Fracture edge of a thermally grown aluminum oxide layer on a high-temperature alloy.*

2 *Sputtered aluminum oxide layer directly on a high-temperature alloy. A titanium electrode was additionally applied (at the top).*

3 *Sputtered aluminum oxide layer on a chromium oxide template layer. Here also with titanium electrode at the top.*



X-ray diffractograms of sputtered Al_2O_3 layers. Above: with chromium oxide template layer; below: without chromium oxide. Deposited in each case under comparable conditions.

Outlook: oxide layers for high-temperature sensor technology

Crack-free and dense barrier layers of aluminum oxide are also an important component for the integration of additional electrical functions on components in a high-temperature environment. Sensors, actuators and electrical information transfer only become possible through high-quality, temperature- and cycle-resistant insulation layers. Good insulation properties are achieved with layer thicknesses of several micrometers. By means of conventional magnetron sputtering, good and adherent layers can be applied. The relatively low deposition rates and the complex process control are, however, disadvantageous. In this respect, reactive gas-flow sputtering offers the possibility of achieving high rates with simple process management. Parallel to the development of the insulation layers, the Fraunhofer IST is also investigating high-temperature sensor layers, e. g. for strain measurement.

CONTACT

Dr. Kai Ortner
Phone +49 531 2155-637
kai.ortner@ist.fraunhofer.de

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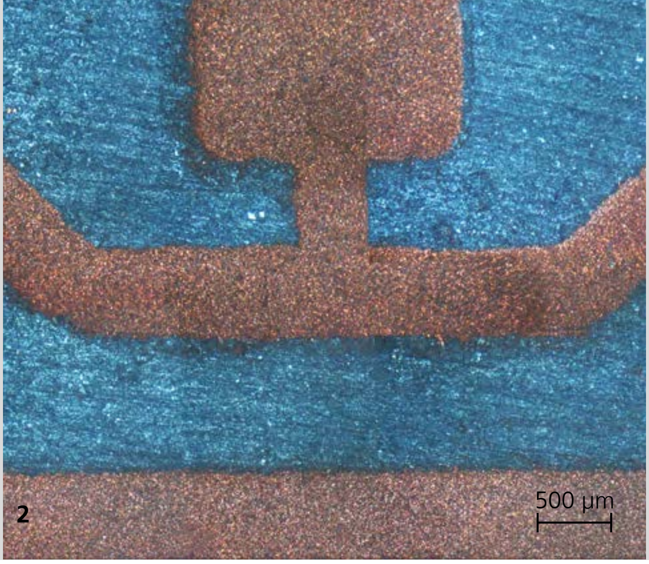

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COLD PLASMA SPRAYING FOR THREE-DIMENSIONAL MOLDED INTER-CONNECT DEVICES

In many industry sectors, three-dimensional molded interconnect devices (MID) are increasingly gaining in importance. The integration of mechanical, electrical and optical functions into a component enables the miniaturization and rationalization of assembly units. Injection-molded parts are predominantly used as the basis for MID components. Under the keyword "additive mechatronization", the development of new processes, for which the additive generation of mechanical structures is combined with electrical functionalization, is currently being brought to the fore.

Advantages over conventional metallization processes

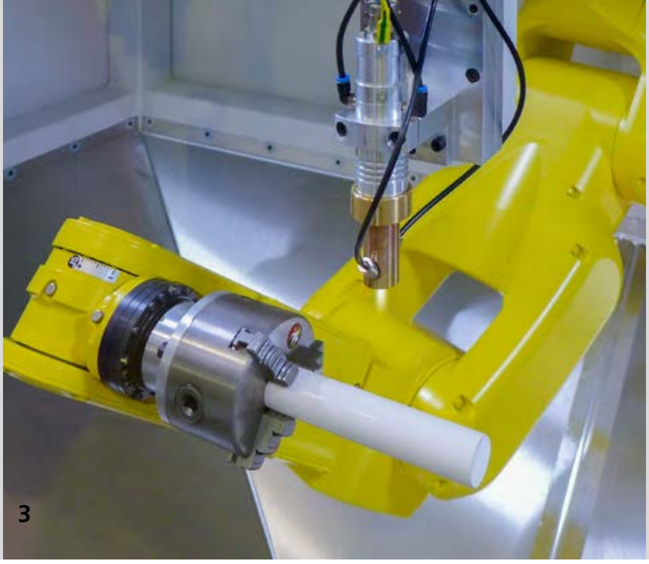
For the selective metallization of polymer surfaces, procedures are primarily applied in which galvanic or wet-chemical process steps are necessary. Through prior laser structuring or drying and sintering processes subsequent to the metallization, the process chain for the established procedures is comparatively extensive. Cold plasma spraying, developed at the Fraunhofer IST Application Center for Plasma and Photonics, enables polymer components to be selectively metallized without wet chemistry and without pre- or post-treatment steps. Figures 1 and 2 show sections of such an MID component.

The technology

The main feature of cold plasma spraying is the utilization of a low-temperature plasma jet, generated from e. g. air or nitrogen. Ultra-fine particles are fed into the process gas and the coating material can be efficiently melted in a low-temperature plasma jet. At the same time the heat transfer to a substrate is minimal. This makes it possible to apply metal coatings to thermally and mechanically sensitive underlays such as polymer and elastomer components, natural materials, such as wood and paper or thin films, without causing damage. The coating is produced without the use of binders. Per passage, layer thicknesses of 5 to 20 µm at a coating speed of approx. 100 mm/s can be realized. The objects are additionally refined under ambient pressure enabling the process to be integrated into more complex inline-capable procedures. Due to the high degree of automation and the kinematic flexibility of robot-aided coating facilities, it is also possible to produce more sophisticated 3D-molded interconnect devices and components (see Figure 1 and 3). This enables the production of a wide range of functional layers for plastics. For example, plastics can be metallized in order to stabilize the substrate or can be equipped with a high electrical or thermal conductivity or antibacterial effect. Further application examples include high current viable coatings, coatings for shielding against electromagnetic interference radiation, flexible conductive tracks, or decorative coatings.

Advantages of MID components created through cold plasma spraying

An important advantage in the application of cold plasma spraying for the production of MID components is that multi-layer systems can be realized. The possible layer materials encompass the most diverse metals and plastics. The wide range of layer materials also enables the combination of widely varying materials, for example: conductive layers can be equipped with protective layers which prevent degradation under mechanically or chemically onerous environmental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1 *Copper conductor path structure on an MID component.*

2 *Microscope image of conductor paths with a width of 500 µm.*

3 *Robot-assisted coating process.*

conditions. Bond-promoting primers can also improve layer adhesion. The targeted combination of individual layers also enables the reduction of local layer tensions, e. g. in transition areas between materials with different thermal expansion behavior.

A further advantage is obtained through the utilization of bimodal composite particles: carrier particles can be coated or loaded with a different material. The use of such composite particles enables the reduction of imperfections or oxide phases and therefore improves the mechanical and electrical properties of the layer. Through the utilization of mixed powders, in which differing metals are present as particles, different material properties can be combined with one another.

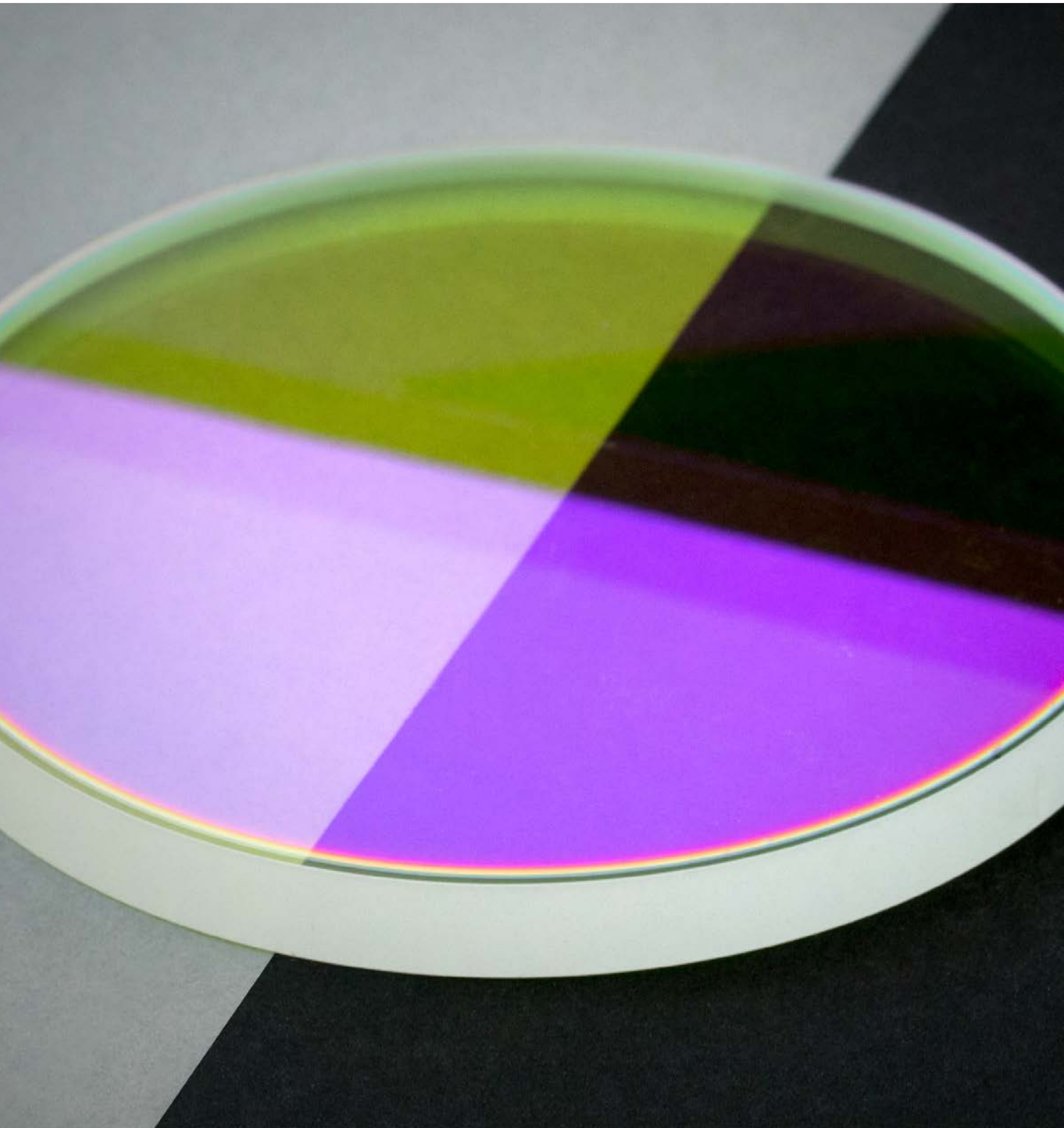
Outlook

At the Fraunhofer IST, cold plasma spraying is continuously being further developed in terms of both equipment and procedures. Currently, the focus is being directed on the integration of inline-capable diagnostic systems such as spray-jet and object temperature measurement, on quality assuring analysis methods, such as spatially resolved eddy current measurement, on process optimization in selective metallization with specific masking techniques, and on a combination of 3D printing processes with cold plasma spraying.

CONTACT

Nils Mainusch, M.Sc.
Phone +49 551 3705-333
nils.mainusch@ist.fraunhofer.de

OPTICS



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

– The development and manufacturing of coatings for optical components

– Systems for the deposition of high-grade optical coatings on flat and curved lenses

– The EOSS® production platform for manufacturing optical filters and laser components

– The development of new materials for intelligent coatings, such as electrically switchable filters

– Highly durable broadband anti-reflective coatings on sapphire and glass

– Micro-structured optical filter coatings for imaging applications

– Optical coatings on plastic surfaces

– Use of simulation in designing and optimizing coating processes and installations in low-pressure systems

– Development of innovative transparent conductive coatings for lighting technology and oxide electronics

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

– In-situ monitoring of coating processes with MOCCA+®

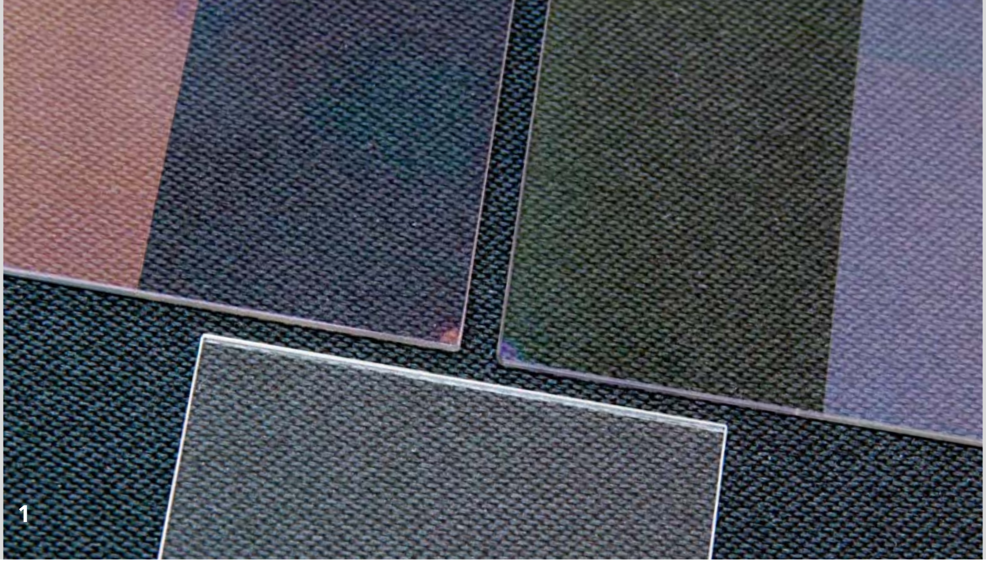
– Mapping system for measurement of ellipsometry, reflection, transmission, flare and Raman spectroscopy on 60×60 cm^2

– Defect analysis of optical layers by means of FIB REM and confocal optical microscopy

– Testing the wear and corrosion resistance of optical surfaces and coatings

This business unit includes clients from companies in the optical industry, the automotive industry, aerospace, manufacturers of displays and data storage media as well as plant manufacturers and contract coating companies.

Dielectric beam splitter of approx. 100 individual layers.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ANTI-REFLECTIVE COATING WITH DIAMONDS

Mostly undetected by the user, anti-reflective coatings (AR) are utilized in many products of daily life today. We encounter them on spectacle lenses, on the screens of smartphones or tablets, in the dashboards of our cars, and – in the age of the "smart home" – also on the control panels of the house management system, the refrigerator and the washing machine in the near future. New products and heightened requirements result in a growing demand for increasingly usable AR coatings with improved scratch and abrasion resistance. The major innovation in the work of the Fraunhofer IST was the enabling of the unsurpassed hardness of diamond to be utilized in optical coating systems for the very first time. The application of diamond promises the greatest possible mechanical strength which can be achieved for optical broadband anti-reflective coatings.

Diamond as an optical layer

For the development of optical diamond coatings, hot filament chemical vapor deposition (HFCVD) technology was applied. This technology was industrially introduced at the Fraunhofer IST on the largest coating surfaces in the world and is the only process with which diamond deposition is conceivable on a size scale relevant for optical components. Its utilization in optical applications, however, requires the production of extremely thin, defect-free coatings in a quality previously unattained for CVD diamond coatings as regards uniformity of coating thickness, transparency and refractive index. Consequently, the focus of the work at the Fraunhofer IST was directed at adapting the HFCVD process steps to the particularly challenging requirement profile of optical coating systems.

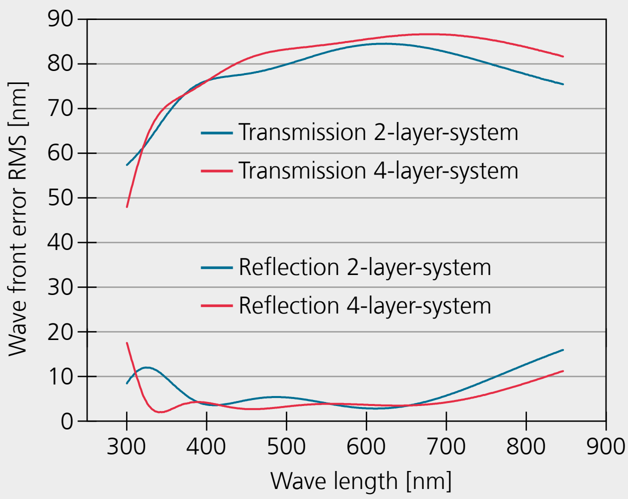
Optical simulation of diamond anti-reflective systems

With the help of optical simulation, differing anti-reflective systems were designed, realized and characterized. The simplest diamond AR layer system consists of a diamond layer and a surface layer of low-refractive silicon dioxide (SiO_2) with coordinated layer thicknesses (2-layer AR system). Furthermore, for an even greater broadband anti-reflective coating in the visible spectral range, four-layer stacks were developed in which, in addition to diamond and SiO_2, tantalum pentoxide (Ta_2O_5) was utilized as the second high-refractive material (4-layer AR system).

Figure 1 illustrates the anti-reflection effect achieved with both diamond AR coating systems. On the left is a 2-layer system, and on the right a 4-layer system, each with diamond as the penultimate sublayer. For comparison, an uncoated quartz glass is shown below. In order to accentuate the anti-reflection effect achieved in each case, the SiO_2 surface layer was omitted in both AR systems in the respective outward-facing third of the sample.

For a quantitative assessment of the achieved anti-reflection effect, transmission and reflection for both coating systems are plotted in Figure 2. As both coated quartz substrates only received the anti-reflective treatment on one side, the reflection can only be reduced to a residual value of 3.4 percent, even with perfect anti-reflective coating. This corresponds to half of the initial value. With the unilateral 2-layer system, a

1 *2-layer (top left), 4-layer (top right) anti-reflective systems compared to an uncoated quartz sample (below).*



Transmission (above) and reflection (below) for unilateral diamond-based anti-reflective coating systems with two or four sublayers (blue and red lines).

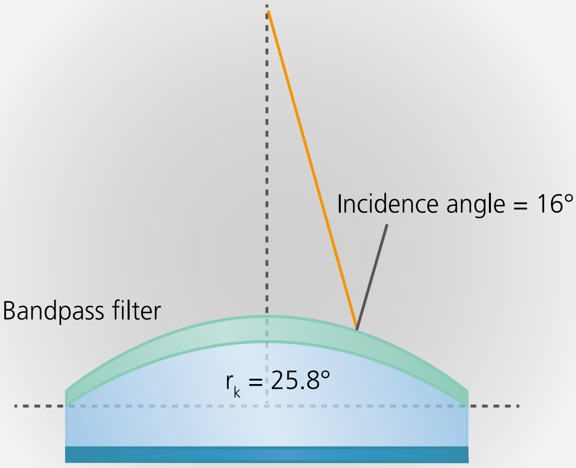
reflection reduction to 4.9 percent was achieved; with the 4-layer system, actually a value of 3.9 percent was attainable. In each case, this was averaged over the spectral range of visible light.

Basis for further development

The diamond-based AR systems realized so far do not fulfill all the requirements yet. The fundamental feasibility and the huge potential of diamond AR systems have, however, been successfully demonstrated, thereby creating the basis for further development within subsequent projects.

CONTACT

Dipl.-Ing. Hans-Ulrich Kricheldorf
Phone +49 531 2155-952
ulrich.kricheldorf@ist.fraunhofer.de



1 Anti-reflective layer

DEPOSITION OF COMPLEX BANDPASS FILTERS ON ASPHERICAL LENSES

A large proportion of optical components are lenses or aspheres with more or less curved surfaces. Generally, broadband anti-reflective coatings are applied. However, through the deposition of complex filters on lenses, it becomes possible to develop novel, very compact optical systems. Due to the resulting weight advantage, that is particularly interesting for so-called LIDAR scanners (Light Detection and Ranging), which can be installed e. g. on flying objects. At the Fraunhofer IST a coating process has been developed that enables lenses to be equipped with a narrow bandpass filter at a wavelength of 670 nm, which exhibits a very wide blocking range of 300 to 1100 nm. The central wavelength is thereby independent of the position on the lens. This was achieved through a special and well-defined layer gradient on the lens.

Complex coatings on 3D surfaces

When coating curved optical components, such as a lens, through physical processes, such as vapor deposition or sputtering, a layer thickness gradient is created. The greatest layer thickness is thereby found at the point where the lens is closest to the substrate and the angle to the source is perpendicular. With interference based filters this leads to a shift of the central wavelength. Furthermore, the curvature of the lens causes a shift in the spectrum as the angle of incidence increases. It is disadvantageous that both effects – the decreasing layer thickness towards the edge of the lens and the increasing angle of incidence – go in the same direction, i.e. are cumulatively negative (see Figure 1). In order to achieve homogenization of the coating and therefore exclude at least one of the two effects, ALD processes (atomic layer deposition) are under development today. For ideal compensation, however, a layer thickness gradient is necessary in which the thickness towards the edge of the lens increases accordingly. Magnetron sputtering with a system such as the EOSS® (Enhanced Optical Sputtering System) developed at the Fraunhofer IST is particularly well suited for this purpose, as it delivers outstanding precision and stability.

Lens with bandpass filter

Within the framework of a study funded by the ESA, a bandpass filter was developed and deposited on a lens with a diameter of 25 mm and a focal length of 50 mm. The central wavelength of the bandpass was 670 nm and should exhibit a very wide blocking range of 300 nm to 1100 nm. For this, 207 layers with a total thickness of 23 µm were ultimately required. The suitable layer thickness gradient on the lens was made possible with the aid of a subrotation and an appropriate mask. The determination of the lens shape was performed with the help of the "Particle-in-Cell Monte Carlo" (PIC-MC) simulation. Following this, the mask could be manufactured without further adjustments.

1 *Schematic view of the bandpass filter.*

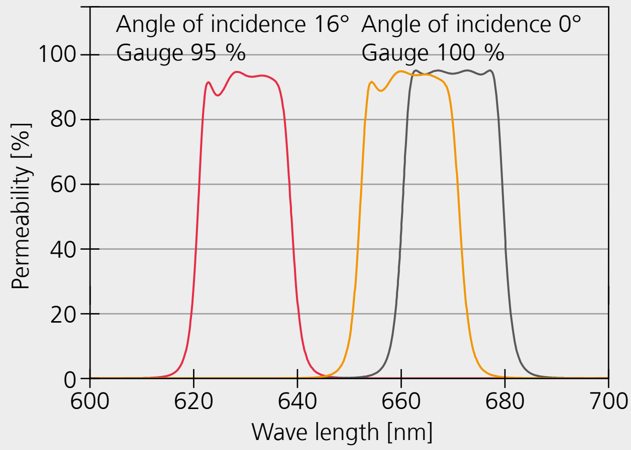
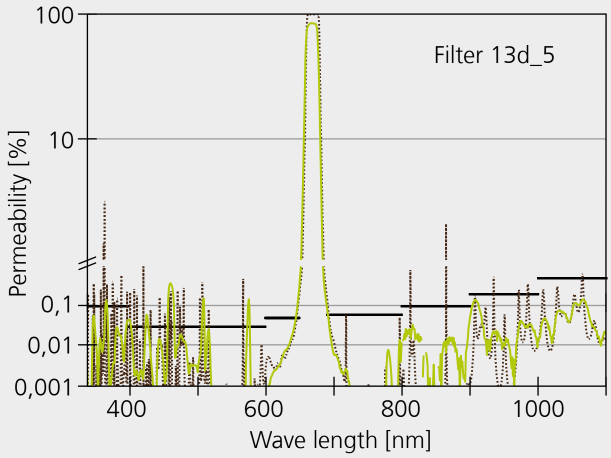


Diagram of the lens to be coated and the expected spectra.



Spectra of the bandpass filter.

Outlook

In the future, an increasing demand for complex coatings on curved surfaces can be expected. Therefore, the further development of EOSS® technology is the subject of further work at the Fraunhofer IST.

The project

The project was funded through the ESA (contract ITT AO/1-8541/15/NL/PS).

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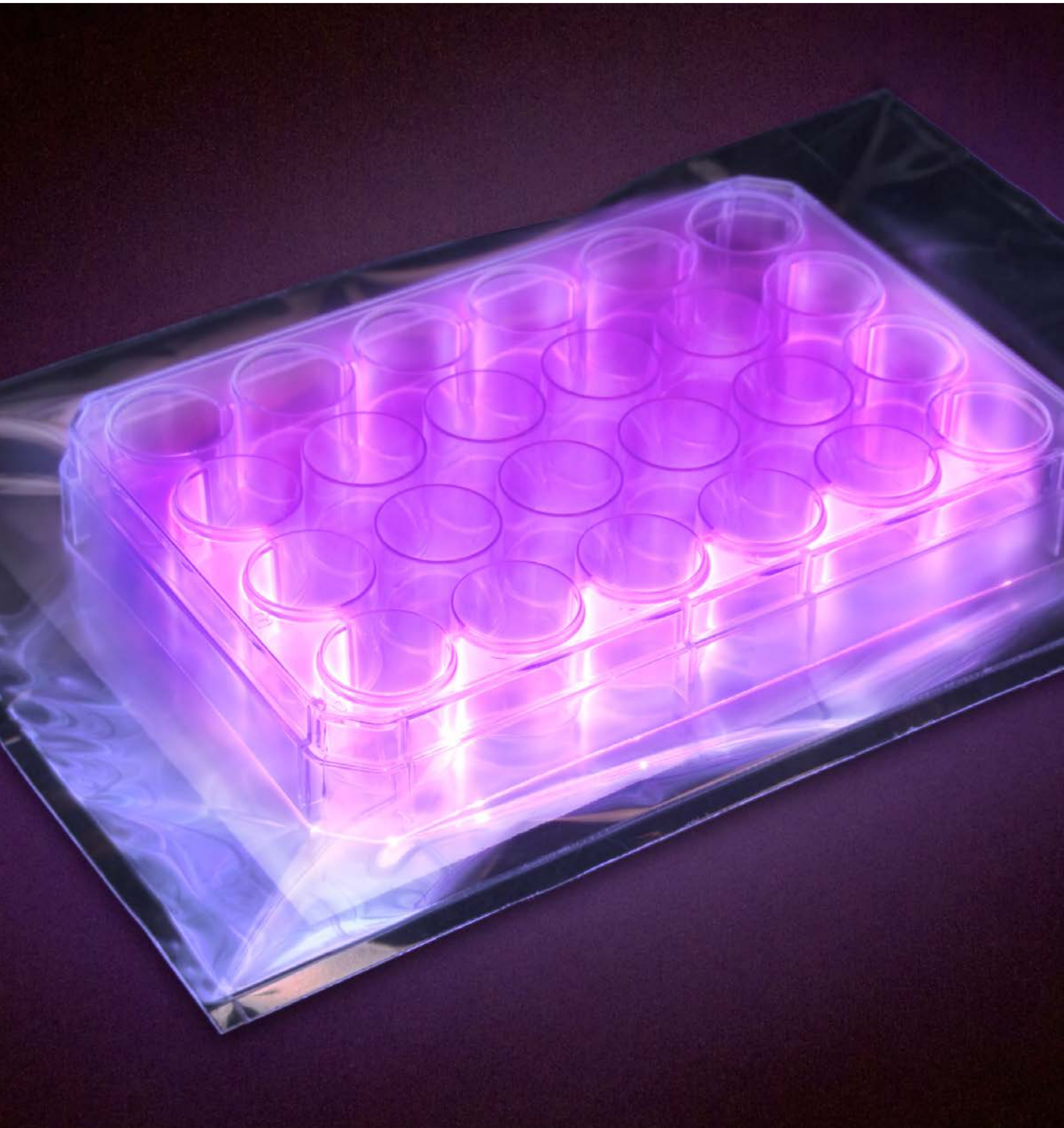
CONTACT

Dr. Michael Vergöhl
Phone +49 531 2155-640
michael.vergöhl@ist.fraunhofer.de

LIFE SCIENCE AND ECOLOGY



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

Cell culture technology and microbiology

- Control of cell adhesion and differentiation
- Control of protein adsorption
- Coupling of antibodies
- Cell transfection and poration
- Medical technology
- Microfluidics
- Biosensors
- Lab-on-a-chip
- Implants
- Sterilization of surfaces and disinfection
- Coating and functionalization of medical disposable articles

Agricultural and food technology

- Disinfection
- Disinfection of packaging
- Barrier coatings
- Anti-adhesive coatings

Water and air purification technology

- Water disinfection and wastewater treatment by means of diamond electrodes
- Photocatalytic air and water purification systems

Self-cleaning

- Standardized test procedures for the neutral evaluation of photocatalytic properties of products

Textile technology

- Halogen-free flame protection for textiles

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

Plasma treatment of a microtiter plate at atmospheric pressure.

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DIAMOND CLEANS DRINKING WATER IN AFRICA

More than 100 million people in rural areas of Southern Africa have no or only restricted access to clean drinking water. With the goal of developing a decentralized and energy self-sufficient solution for drinking water treatment for rural regions in Africa, the Fraunhofer IST is coordinating a project funded by the European Union under the title “Self-Sustaining Cleaning Technology for Safe Water Supply and Management in Rural African Areas”, or SafeWaterAfrica for short. The technological basis for the water disinfection is electrochemical oxidation using diamond-coated electrodes developed at the IST.

Water treatment and disinfection

Rivers and wells, which are primarily used as sources of drinking water in Southern Africa, often contain high concentrations of organic pollutants, heavy metals and pathogens. In the first step of the water treatment, organic constituents and heavy metals are removed using a combination of electrocoagulation, flocculation and filtration. Subsequently, diamond-coated electrodes are utilized for disinfection in order to kill fungi, algae, bacteria and viruses with the aid of electrochemical oxidation (see Figure 1). The special challenge lies in designing components able to withstand the conditions prevailing in remote regions.

In September 2018, the first demonstrator built by South African partners was erected in Waterval near Johannesburg (see Figure 2). Solar cells and a battery will enable self-sufficient operation independent of unreliable or non-existent power networks.

Improved long-term stability of diamond electrodes

Within the framework of the project, the Fraunhofer IST developed a new concept for improving the long-term stability of diamond electrodes. The novel diamond electrodes consist of silicon base bodies with a coating of electrically conductive diamond which is only a few micrometers thick. In order that diamond growth is able to take place in the hot-wire CVD process, a pretreatment step, known as nucleation, is required. The denser and more homogeneously the diamond nuclei are applied to the base body, the faster the growth of a defect-free diamond layer and the longer the achievable service life.

Nucleation through bombardment with hydrocarbon ions

In the “SafeWaterAfrica” project, the “Hot Filament Bias Enhanced Nucleation (HFBEN)” process was used for the first time for the nucleation of the diamond electrodes. Nucleus formation takes place directly in the coating reactor through bombardment with hydrocarbon ions which are created in an additional plasma. The advantage of the HFBEN process is that it produces particularly high and uniform nucleus densities, thereby enabling the growth of low-defect diamond coatings with potentially improved service life.


3

1 Disinfection unit of the demonstrator with three electrochemical cells connected in parallel with diamond electrodes (housing inscription "SafeWaterAfrica").

2 Demonstrator for water treatment during the installation phase in South Africa.

3 Electrode after Hot Filament Bias Enhanced Nucleation and a short diamond deposition (the color is caused by interference).

Outlook

Following the successful installation of the first demonstrator, a second demonstrator is now being set up in Mozambique. In a test phase with a duration of several months, the demonstrators will be tested as regards water quality, failsafe performance and operating costs. Simultaneously, business models will be developed in order to transfer the technology to real application following conclusion of the project in November 2019.

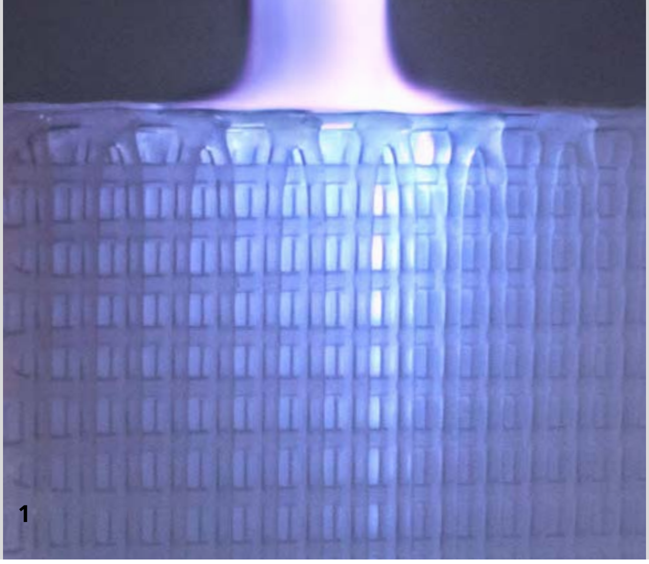
The project

This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement no. 689925.

CONTACT

Dr. Jan Gäbler
Phone +49 531 2155-625
jan.gaebler@ist.fraunhofer.de

Dr. Markus Höfer
Phone +49 531 2155-620
markus.hoefer@ist.fraunhofer.de



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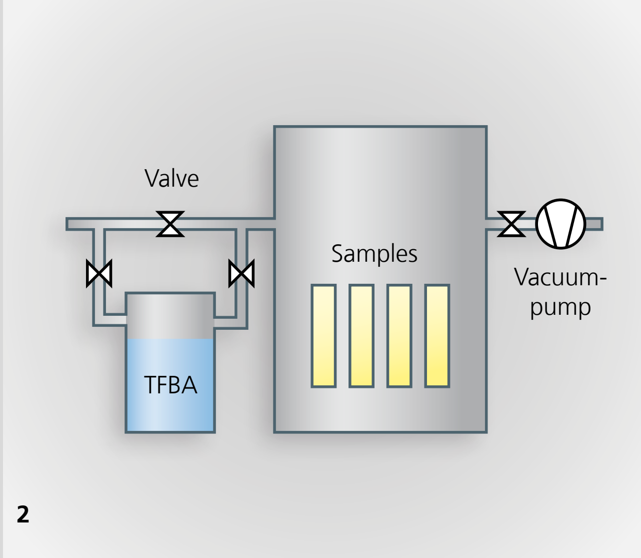

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CHARACTERIZATION OF COATED POLYMER IMPLANT STRUCTURES

3D-printed porous polymer framework structures, so-called scaffolds, present an interesting new approach for the treatment of missing bone fragments. For the ideal ingrowth of new bone cells, chemical modification of the polymer surface is necessary. This can be performed through, for example, coating with an atmospheric-pressure plasma jet in which layer-forming precursors with the desired functional chemical groups are utilized. In order to optimize the deposition processes and to identify important influencing variables it is necessary to measure the chemical groups. Within the framework of a project funded by the European Union, the Fraunhofer IST has therefore been investigating methods for the characterization of functional coated polymers.

The approach

Nucleophilic groups such as amines and imines react selectively with 4-trifluoromethyl benzaldehyde (TFBA). This can be exploited in order to determine their density on surfaces. For this purpose, the samples to be measured are first exposed to TFBA vapors and subsequently ventilated (see Figure 2). The quantity of remaining TFBA molecules per area can be analyzed by means of various spectroscopic methods such as Fourier transform infrared spectroscopy with attenuated total reflection (ATR-FTIR), X-ray photoelectron spectroscopy (XPS) or electron probe microanalysis (EPMA) and is a measure of the density of the nucleophilic groups. In the case of three-dimensional, porous substrates, the penetration depth of the coating and the homogeneity in the depth are also of great interest. For the characterization of the penetration depth of coatings with 3-aminopropyl trimethoxysilane (APTMS) in scaffolds, these were derivatized immediately following coating with TFBA and were subsequently sliced. Along the cut edge, both the layer thickness and the density of the groups were determined by means of EPMA.

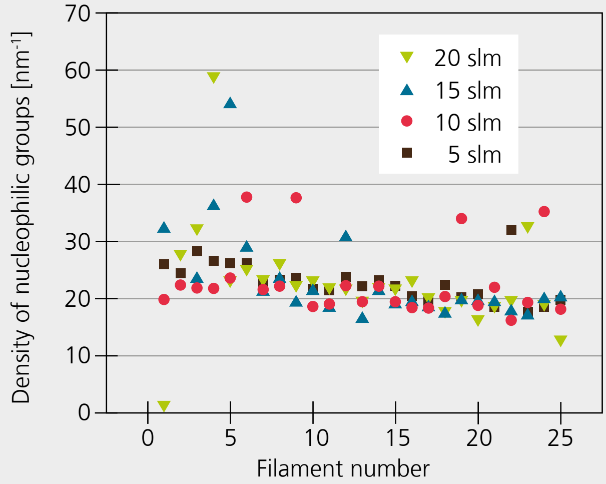
The results

The investigations into APTMS coatings at the Fraunhofer IST have shown that scaffold structures with a thickness of 10 mm can be completely coated with a plasma jet without a significant decrease in layer thickness or group density (see Figure 1). Through higher process gas flows, higher layer thicknesses are achieved.

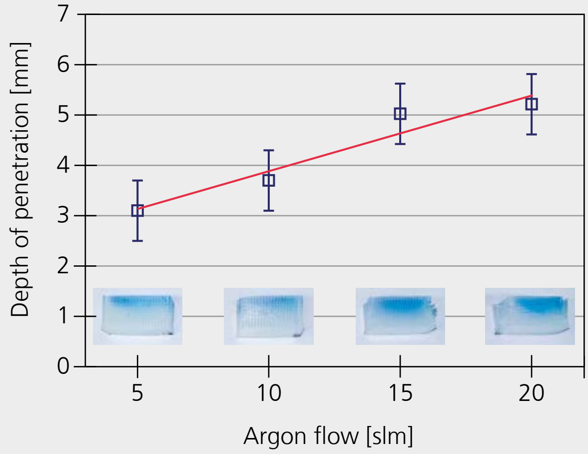
For the investigation of electrophilic MSA-VTMOS layers (maleic anhydride and vinyltrimethoxysilane as plasma copolymer), the coated samples were stained with methylene blue solution. Via electrostatic interactions, this dye binds to the carboxyl groups of the MSA. The coating did not penetrate the scaffold completely. As shown in the diagram on the next page (below), the observed penetration depth was only 4 to 6 double layers of the scaffold filaments. The cause could be in the considerably lower vapor pressure of the MSA. Again, an increased process gas flow can also increase the penetration depth here.

1 Penetration of an additive manufactured structure.

2 Experimental setup for TFBA derivatization.



pp-APTMS: Layer thickness and group density in dependence on penetration depth.



Electrophilic MSA-VTMOS layers dyed with methylene blue.

Outlook

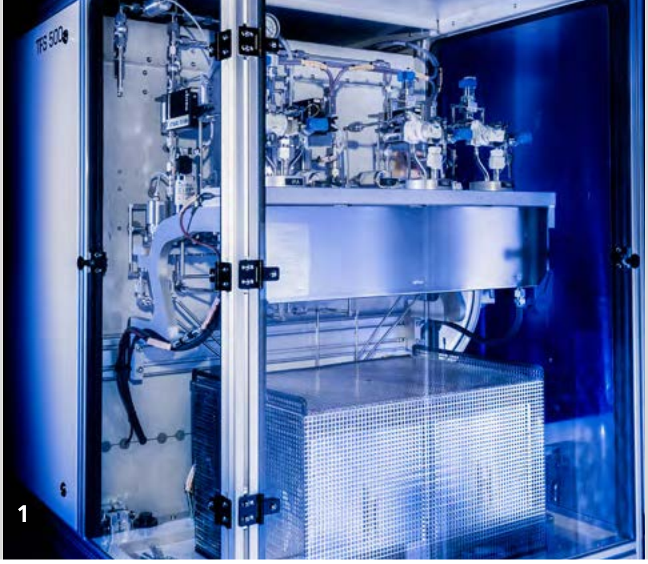
With the applied techniques, the coatings on the scaffold structures could be verified, together with their chemical activity. Both are important prerequisites for further optimization of the process parameters and for pursuing in-vitro and in-vivo investigations into cell growth.

The project

The project "Functionally graded Additive Manufacturing scaffolds by hybrid manufacturing", in short "FAST", was funded via the funding agreement No. 689925 from the European Union research and innovation program Horizon 2020.
http://project-fast.eu/en/home

CONTACT

Dr. Thomas Neubert
Phone +49 531 2155-667
thomas.neubert@ist.fraunhofer.de



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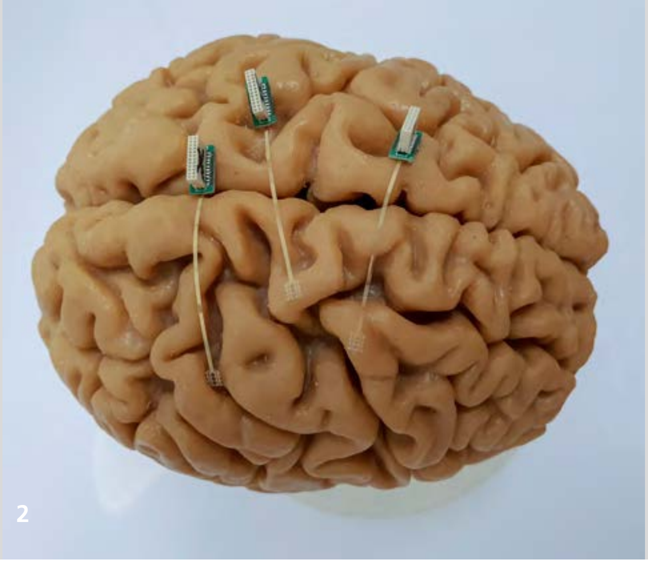

2

BRINGING MEDICAL INNOVATIONS MORE SWIFTLY TO THE PATIENT

Translation in medicine, i.e. the transfer of results from preclinical research into clinical development, is fraught with considerable hurdles. The financial costs associated with special technologies, which arise during the long period of conformity evaluation (CE) prior to the market entry of a medical product, often hinder - particularly in the case of start-up companies which are still less strong financially - the entrepreneurial decision to introduce medical technology innovations onto the market and therefore to the patient. The joint project "Translationale Fertigungsplattform Medizininnovation" (translational production platform for medical innovation), funded by the State of Lower Saxony via the NBank, aims at breaking down this barrier by means of a new structural approach for accelerating the transfer of innovation. For the first time, this provides SMEs and start-ups with simple access to existing special technologies for the manufacture of innovative medical products.

Production process validation

Within the framework of the funding project, a total of five partners, the Institute for Microtechnology at the TU Braunschweig, the Lower Saxony Centre for Biomedical Engineering, Implant Research and Development (NIFE), the HAWK University of Applied Sciences and Arts, the Fraunhofer Institute for Toxicology and Experimental Medicine ITEM and the Fraunhofer IST, are exemplarily developing a process for the efficient establishment of a production platform for a medical product. The example product is a flexible electrode, the so-called "Flextrode", which is used to identify epileptogenic tissue, i. e. nerve tissue in the brain which can trigger epilepsy.

Atomic layer deposition for medical applications

Within the framework of the project, the Fraunhofer IST is developing the coating technology on the basis of the so-called atomic layer deposition (ALD) for the production of nanometer-thick diffusion barrier layers for implants with deep-set micro-undercuts or vertical material interfaces. ALD technology is characterized in particular by the fact that highly conformant and uniform coating systems can be deposited on geometrically complex surfaces with excellent reproducibility. The validation of the manufacturing process is performed in accordance with the DIN EN ISO 13485:2016 standard, in order to prove the conformity with the fundamental safety and performance requirements pursuant to the "Medical Device Regulation" and is divided into installation, function and performance qualification of the production lines.

Our service

The Fraunhofer IST offers both companies and universities that do not have their own corresponding infrastructure the use of the facility for atomic layer deposition – which is qualified for medical technology – within the framework of joint projects. This is of particular interest for small companies and spin-offs or start-ups, as it provides them with access to a facility approved for the manufacture of medical products, without the need for large investments. In this way, the IST contributes towards both the reduction of obstacles to innovation and the acceleration of medical innovations being brought to the patient.

1 *The ALD process is capable of coating three-dimensional objects and complex geometries with high conformity and homogeneity.*

2 *Demonstrator for neuro-transplants for the identification of epileptogenic tissue.*

The project

The described results were achieved within the "TransPlaMed" project, funded by the European Regional Development Fund (ERDF) and the Lower Saxony program area "Stärker entwickelte Region" (Stronger developed region, SER).

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CONTACT

Tobias Graumann, PMP
Phone +49 531 2155-780
tobias.graumann@ist.fraunhofer.de

SERVICES AND COMPETENCIES

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

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

In addition, the Fraunhofer IST provides recognized competencies for a variety of coating systems. The institute offers a broad spectrum of cross-sectional services: Surface pretreatment, thin film development, surface modification, process technology (including process diagnostics, modeling and control), digital process automation, cyber-physical product and production systems, sustainable factory systems and life cycle management, energy storage systems, surface analysis and thin film characterization, training, application-oriented film design and modeling, simulation, system design, device and equipment manufacturing and technology transfer.

Demonstrator of a mobile measuring gun with luminescent polymeric carrier.

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LOW PRESSURE PROCESSES AND ATMOSPHERIC PRESSURE PROCESSES

Physical Vapor Deposition (PVD)

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

Chemical Vapor Deposition (CVD)

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

Plasma diffusion

- Nitriding / Carbonitriding
- Oxidizing
- Boriding

Atmospheric pressure plasma

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

Electrochemistry

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

Laser technology

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

Layer-by-layer processes

- Polyelectrolyte coatings
- Biofunctional coatings
- Chemical derivatization

ENERGY STORAGE AND SYSTEMS

Energy Storage Development and Production Engineering

- Development of mobile and stationary energy storage devices and systems through to industrial maturity
- Formulation and production strategies for solid-state batteries*
- Scalable manufacture and fabrication of materials for energy storage systems*
- Particle and surface coating
- Surface functionalization
- Characterization of particles, powders and suspensions*
- Electrode manufacture*
- Cell characterization and safety*

Sustainable Factory Systems and Life Cycle Management

- Battery cell production*
- Model-based planning and operation of battery production systems
- Simulation from product to factory scale
- Networking of virtual models with real battery production in cyber-physical production systems (CPPS)
- Data mining and data analytics along the battery process chain
- Ecological-economic life cycle analyses

*in cooperation with the Battery LabFactory Braunschweig (BLB).

1 *Magnetron sputtering system for short-cycle coating.*

2 *Plasma printing in a roll-to-roll process.*

3 *Electrodes for the production of battery cells.*

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2

COMPETENCE COATING SYSTEMS

Friction reduction and wear protection

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

Electrical and optical coatings

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

Micro- and nanotechnology

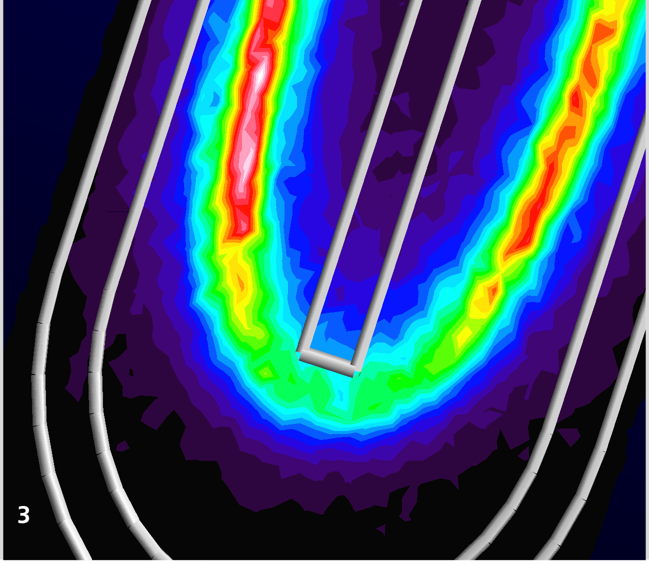
- Thin-film sensor technology
- Microtechnology
- Nanocomposites
- Control of coating adhesion
- Structured surface coating and activation

Biofunctionalization

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

Photocatalysis

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



FURTHER COMPETENCIES

Pretreatment and functionalization

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

Product and production systems

- Life Cycle Management
- Sustainable factory planning
- Design of process chains and production systems

Simulation

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

Analytics and quality assurance

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

1 *Sputtered sensor structures in the tread of a ball bearing.*

2 *Black coating with dielectric beam splitter layer for use in space applications, e. g. in spectrometers.*

3 *Simulation of the electron distribution on a target.*

1

DEPTH PROFILE ANALYSIS ON CURVED SURFACES WITH SIMS

Secondary ion mass spectroscopy (SIMS) is a technique used to determine the chemical composition of thin films as a function of the depth. The surface of the specimen is removed layer by layer using an ion beam. SIMS achieves a depth resolution of just one nanometer and detection limits of less than one part per million. However, quantifying the depth profiles of thin films is challenging because of so-called matrix effects. This means that with SIMS, the calibration factors for the concentrations change with the chemical composition of the specimen, i.e. the matrix. Furthermore, curved surfaces of technical samples pose a particular challenge since they can falsify the results.

Quality assurance for hard material films on cylindrical parts

Today the automotive and tool industries coat large numbers of small, cylindrical components, such as injection needles, piston pins, pistons, drill bits, milling cutters, etc. with hard material coatings such as DLC (diamond-like carbon), tungsten DLC, CrN, TiN, CrAlN, or TiAlN (see Figure 1). For the quality assurance of these products it is crucial to measure the hydrogen content (H) of the DLC and W-DLC films or to determine the exact ratio of metal to nitrogen not only at the surface but also in buried layers, multilayers, or gradient layers. By means of quantitative SIMS depth profile analysis this is possible if the Cs-cluster method is used to reduce the matrix effects and adapted standards are applied.

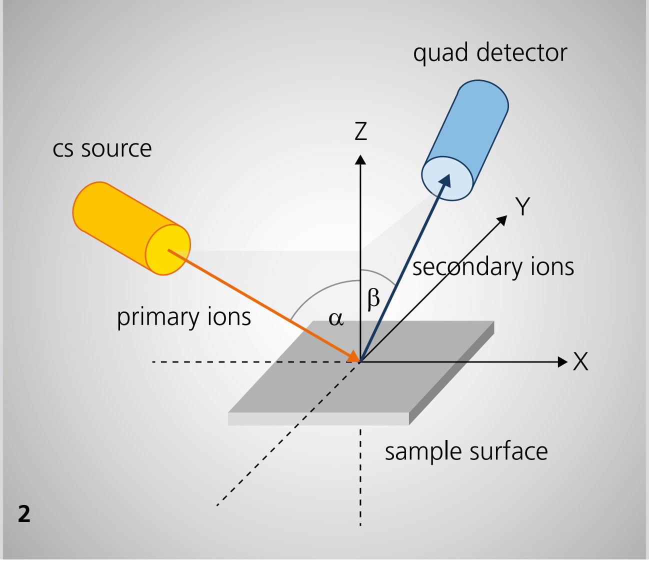
Influencing factor – angle of incidence

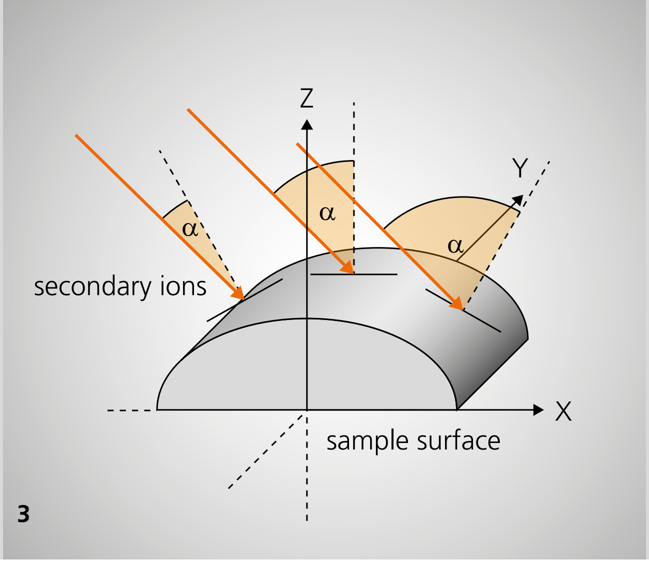
The results of SIMS measurements not only depend on the chemistry of the specimen but also on the impact angle of the ion beam and the take-off angle of the mass spectrometer (see Figure 2). If the ion beam does not hit the highest point of small cylindrical samples with diameters of 2 to 10 mm, the angle of incidence changes (see Figure 3). For a cylinder with a diameter of 2 mm such as an injection needle, an incidence deviation of just 0.2 mm causes the impact angle or take-off angle to deviate by more than 10°. Since the specimens are optically adjusted and the DLC films are also entirely black, such or even larger adjustment errors can easily occur. This problem plays a special role with curved surfaces.

Angle dependence of SIMS measurements

In a representative study on the aforementioned hard material films, the quantification error as a function of the impact angle α and the take-off angle β was determined in a range of approximately 20° to 60°, where 45° is the standard angle for flat specimens.

It was found that the raw counting rates for Cr, Ti, Al, W, and N vary by a factor of 5 to 30 with the angle, the count rates of H and C on the other hand considerably less. The dependence on the take-off angle β is similar in size. For quantification using so-called relative sensitivity factors (RSF), the ratio of the counting rates for the elements to the matrix element carbon (C) or nitrogen (N) is determined respectively. This value is proportional to the chemical composition. Thus, its variation with the angle α and β indicates the possible quantification





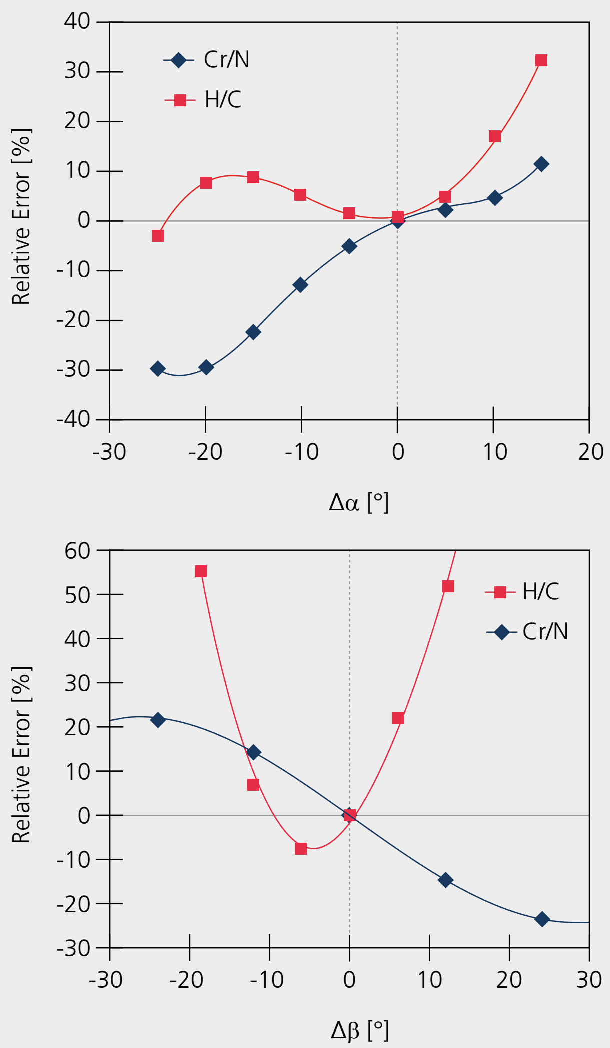
1 *Examples of cylindrical SIMS specimens with three DLC films and a CrAlN film (drill bit).*

2 *Impact angle α and take-off angle β of the ion beam in SIMS.*

3 *Position-dependent variation of the impact angle with curved surfaces.*

error. The diagram on the next page shows exemplarily the error for the H/C ratio of a DLC film and the Cr/N ratio of a CrN film. Especially with H, an angle error of 10° can lead to quantification errors of up to 20 percent, which means e.g. that 25at% H instead of 20 at% H is detected. The relative error is usually lower for nitride film systems (10 percent).

The studies show that extremely careful adjustment of the measuring position is of special importance with curved samples. With cylindrical specimens, the ion beam has to be adjusted precisely to the cylinder's highest horizontal point. Based on the results, for known, well-defined tilt angles, e. g. a blade cutting edge, the angle dependence can be corrected using the known angle dependence.



Quantification error in percent for hydrogen in DLC and chrome in chrome nitride films as a function of the impact angle α and take-off angle β.

CONTACT

Dr. Kirsten Schiffmann
Phone +49 531 2155-577
kirsten.schiffmann@ist.fraunhofer.de

1

A NEW APPROACH TO THE GALVANIC DEPOSITION OF ALUMINUM

In the world of technology, aluminum is a popular material with many positive properties. Not only does it offer very good corrosion protection, it is also distinguished by good electrical properties and a high reflection capacity. The range of applications is correspondingly varied: from foil applications in the food industry to numerous components in the sanitation field and optical applications, aluminum is the material of choice.

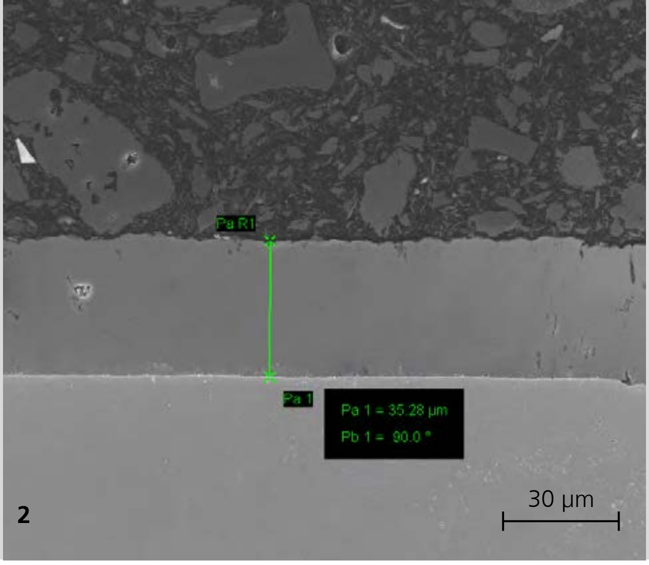
Aluminum films

While solid aluminum can be manufactured and machined extremely well, e. g. with casting or forging processes, the processes for depositing aluminum films are limited. In most cases, vacuum processes such as vaporization or sputtering, i.e. processes involving the physical deposition from the gas phase (PVD, physical vapour deposition) are used. The galvanic processes for deposition out of aqueous media, popular for other metals such as copper, nickel or chromium, are not suitable for aluminum since this material is not as electrochemically pure.

Aluminum deposition from organic solvents, on the other hand, has already been developed successfully to the point of technical feasibility. However, costly safety precautions are required since the solvents are flammable. An alternative, which Fraunhofer IST was involved in developing, is the galvanic deposition of aluminum out of so-called ionic fluids. These are salts, some of which are liquid at room temperature. They are neither flammable nor, according to current scientific knowledge, toxic. However, they also have significant disadvantages: They are highly hygroscopic (water-absorbing) and therefore have to be protected from air moisture at considerable expense. Another significant disadvantage is their remaining very high cost.

A new approach

A new approach by Fraunhofer IST for developing a safe, economical process for aluminum coating is the galvanic deposition of aluminum from so-called deep eutectic solvents. These are eutectic salt melts with a melting point near room temperature. In the case of aluminum deposition, the salt melt consists of a mixture of aluminum chloride and dimethyl sulphone ($AlCl_3/DMSO_2$). Unlike ionic fluids, $DMSO_2$ is a very



1 *Structured aluminum deposition on copper.*

2 *Scanning electron microscope image of a polished cross section of an aluminium film on copper.*

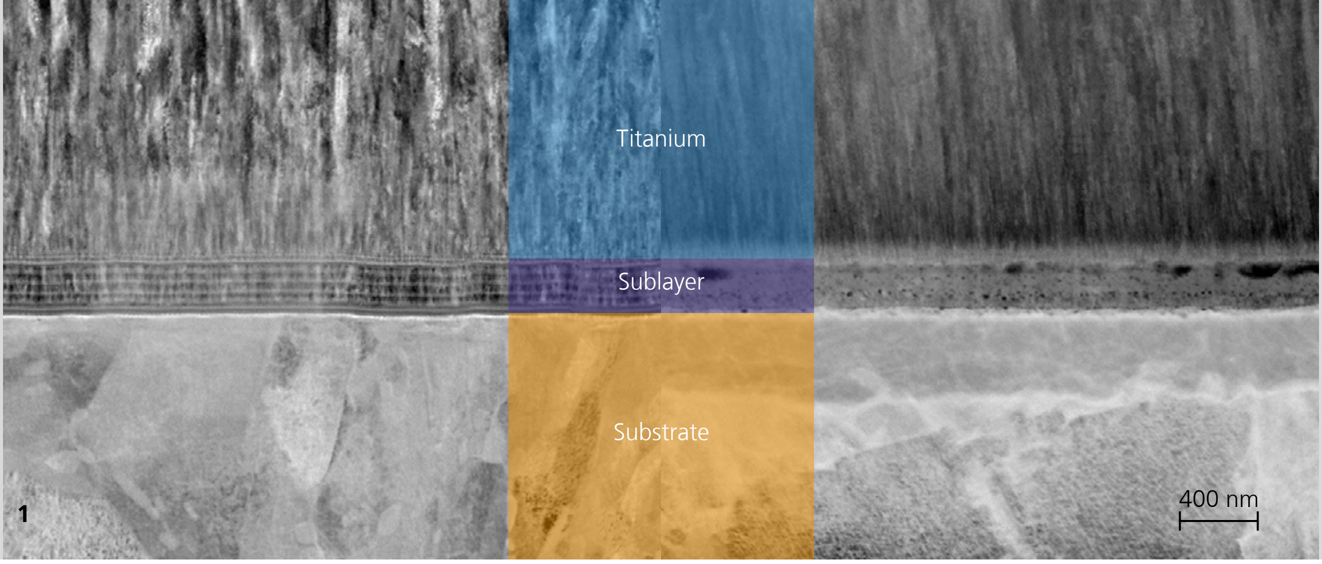
cheap substance which among other things is also used as a food additive. Like the ionic fluids, the eutectic mixture is also not flammable, but also highly hygroscopic, so that likewise it can be used under the exclusion of air moisture only. The first experiments at Fraunhofer IST are promising: Consistent aluminum films with a thickness of over 30 µm and good adhesion were produced successfully.

Outlook

In order to qualify the process for industrial use, it must be "simplified", i.e. it must also work without the protection of a glovebox. One of the biggest challenges is to design the transition from an aqueous pre-treatment, i. e. cleaning and activation, to non-aqueous film deposition without passivation occurring again in the interim.

CONTACT

Dr. Andreas Dietz
Phone +49 531 2155-646
andreas.dietz@ist.fraunhofer.de



THERMODYNAMIC MODELING OF MATERIAL ALLOYS USING THE CALPHAD METHOD

Computer-aided simulation is a key component in today's research and development work. This also increasingly applies to the materials sciences. With the CALPHAD method (CALculation of PHAse Diagrams), which is based on the calculation of phase equilibrium states and thermodynamic properties in a defined system, material properties can be calculated. This enables, for example, testing alloys regarding their suitability for specific procedures and applications, the development of a better understanding of processes taking place within the material, and a targeted optimization of alloy compositions and layer systems.

Electron beam treatment of $Ti_{(1-x)}Al_xN$ layers on quenched and tempered steel

At the Fraunhofer IST, the simulation software Thermo-Calc was utilized for the electron beam treatment (EBH) of $Ti_{(1-x)}Al_xN$ layers on quenched and tempered steel. Interesting insights into material properties were thereby obtained. Prior to electron beam treatment, the focused ion beam (FIB) specimens exhibit a periodic morphological layer structure which is caused by substrate rotation during the coating process. Over the course of the EBH, this structure of the sublayer disintegrates and a matrix structure with globular inclusions is formed (see Figure 1). The processes which lead to the phenomenon can be explained with the help of a chemical analysis and simulation by means of Thermo-Calc.

The analysis

Phase and state diagrams for the different areas within the material, which were initially created using the Thermo-Calc software, show that the microstructures of the compound layer and the sublayer differ substantially. The TiAlN layer consists largely of cubic face-centered solid solution and aluminum nitride, while in the sublayer, a hexagonal close-packed solid solution and a Ti_2N phase are primarily formed. The variation of the element concentrations by the measured values shows, that for certain chemical compositions, liquid aluminum precipitates at temperatures from around 1000 °C (see adjacent diagram above). Local temperatures of considerably more than 1000 °C can indeed be achieved through the influence of the electron beam, so that aluminum precipitates in the corresponding areas and subsequently resolidifies. Moreover, further material properties, such as solidus temperature and density, were calculated in dependence on the chemical composition. The progression of the solidus temperature then attains a low point between 35 and 45 at% nitrogen (see adjacent diagram below), where it corresponds approximately to the precipitation temperature of the liquid aluminum.

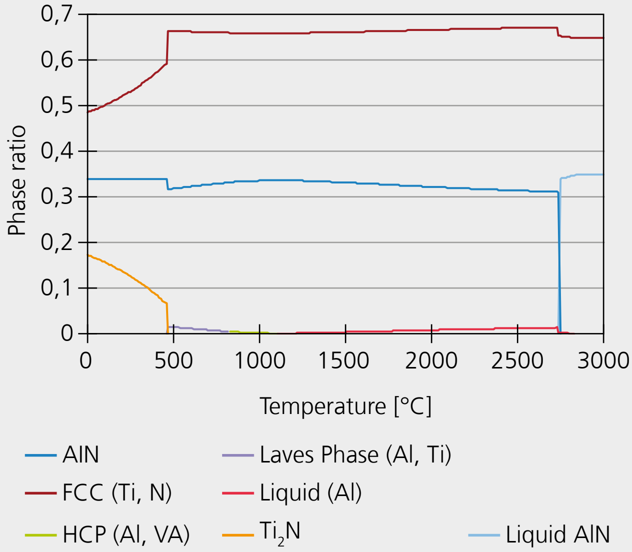
1 *FIB specimen of the TiAlN layer before (left) and after (right) electron beam treatment.*

The results

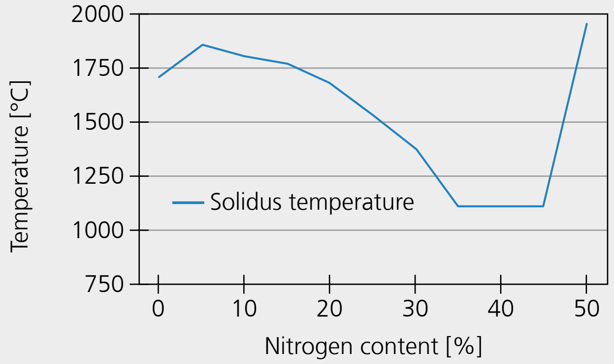
The modeling of the processes during the EBH of TiAlN layers by means of Thermo-Calc provides a plausible explanation for the observed structural changes. It suggests that small volumes are heated by the electron beam to local temperatures above the solidus temperature, so that liquid aluminum is precipitated, solidifies and remains in the cross section as globular precipitates with lower density.

Outlook

The CALPHAD method is applied as support in other projects. The simulation of diffusion processes in complex materials with the help of the additional software DICTRA is thereby gaining increasingly in importance.



Property diagram (above) for the ternary system TiAlN and solidus temperature in dependence on the nitrogen content (below).



CONTACT

Julian Vogtmann, M.Sc.
Phone +49 531 2155-657
julian.vogtmann@ist-extern.fraunhofer.de

NAMES, DATES, EVENTS

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TRADE FAIRS, EXHIBITIONS, CONFERENCES

Hannover Messe 2018

Digitalization is a topic that affects and moves all industries. Thus, at this year's Hanover Trade Fair the Fraunhofer IST appeared for the first time in the area of "Digital Factory" at the joint Fraunhofer booth "Digital Solutions & New Materials". With its work on process simulation in the area of thin-film technology the Fraunhofer IST demonstrated to what extent digital solutions can facilitate and accelerate the development of innovative materials and surfaces. Furthermore, the institute presented possible applications of thin film sensors in the area of Industry 4.0 not only in hall 6, but also at the main Fraunhofer booth "Factory of the Future" in hall 2.

Internationale Luft- und Raumfahrtausstellung ILA 2018

As one of six institutes of the Fraunhofer Space Alliance, the Fraunhofer IST was participating again in the International Aerospace Exhibition ILA at the ExpoCenter Airport in Berlin. In the "Space Pavilion", the Fraunhofer IST presented mirrors of carbon fiber reinforced plastic and optical filter for space applications as well as metallized CFRP waveguides for antennas of the "Sentinel mission".

SVC TechCon 2018

Several scientists of the Fraunhofer IST took part at this year's SVC TechCon which was held in Orlando, Florida and contributed with a variety of lectures to the scientific program.

Optatec 2018

At the Optatec 2018 the Fraunhofer IST presented its current results in the field of optics and showed various optical filters, which were produced by the sputtering system EOSS® (Enhanced Optical Sputtering System) as well as coatings and optical components for space applications. The innovative sputter platform EOSS®, with which up to ten optical interference filters with a diameter of 200 mm can be produced simultaneously with the highest precision as well as highly complicated layer designs with several 100 layers with high uniformity can be deposited, was exhibited as a scale model.

9th International Conference on High Power Impulse Magnetron Sputtering (HIPIMS)

The Fraunhofer IST organized the annual International Conference on High Power Impulse Magnetron Sputtering (HIPIMS) in cooperation with the Sheffield Hallam University and INPLAS e. V. competency network. Over time it has established itself as a meeting place for scientists from all over the world who exchange information about the latest results and trends in the field of innovative plasma surface engineering. Once again representatives from the Fraunhofer IST were participating in the conference program with numerous presentations this year.

1 *View of the Fraunhofer joint booth "Sparking the Future" in Hall 2 at the Hannover Messe 2018.*

69th International Astronautical Congress IAC

The demands on materials in aerospace technology are extremely high. Greatest weight reduction, the stress caused by very rapidly changing temperatures and the enormous mechanical loads require the development of high-performance coatings. As part of the Fraunhofer SPACE Alliance, the Fraunhofer IST presented the latest coating developments for space applications:

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EVENTS, COLLOQUIA, WORKSHOPS

Science Day

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

Distinguished Chair Professorship at Feng Chia University in Taiwan

The Feng Chia University in Taichung, Taiwan appointed Dr. Ralf Bandorf, manager of the group "Highly Ionized Plasmas and PECVD" at the Fraunhofer IST as "Distinguished Chair Professor FCU". In doing so the university pays tribute to the longstanding good scientific cooperation. Therefore, on June 1st 2018, a Memorandum of Understanding was signed that sealed the partnership between Fraunhofer Institute for Surface Engineering and Thin Films IST and Feng Chia University, which has been existing since 2014. A successful cooperation has developed especially in the field of high power impulse magnetron sputtering (HiPIMS), an innovative coating technology and the special field of Ralf Bandorf.

Another step in growing the German-Taiwanese cooperation has been made only a few months later. On November 16 2018, the Feng Chia University and the Fraunhofer IST opened the Institute of Plasma (IoP) in Taichung collectively. The aim of the joint institute is to develop solutions in the field of plasma technology tailored to the requirements of the Taiwanese market. For this purpose, a new coating plant has already been set up and put into operation in one of the three laboratories of the new institute.

Fraunhofer Science Campus 2018

Science is becoming more and more female. The Fraunhofer Society wants to support this trend and invited female scientists to the "Fraunhofer Science Campus" from September 24 to 26, 2018 in Braunschweig and Hannover. In order to increase the amout of women scientists at Fraunhofer, the Science Campus was launched together with several partner universities.

In September of this year the Fraunhofer Science Campus took place at the four Fraunhofer Institutes IST, ITEM, IWES und WKI in Braunschweig and Hannover for the first time. During the three-day event, students and graduates of mathematics, informatics, natural sciences and technology, in short: MINT, gained an insight into different research fields and the work in applied research.

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The approx. 40 participants of the Science Campus had the opportunity to look over the scientists' shoulders at the institutes, to deepen their knowledge in selected seminars and lectures, to establish contacts and to get a valuable guide for their career planning in high-quality workshops from "Design Thinking" to "Conversation Techniques" and "Business Manual".

The main topics at the Fraunhofer IST are ranging from mechanical engineering to medicine. The participants of the Science Campus learned the crucial role of coating and surface technology in diamond-sharpening knives, in diamond water purification – without chemicals, intelligent washers or tools that measure force and temperature or a laboratory in the bag that is suitable for stem cell production.

New member of the management at the Fraunhofer IST

Since 1st November 2018 Professor Dr. Christoph Herrmann, dean of the Faculty of Mechanical Engineering, has been director at the Fraunhofer Institute for Surface Engineering and Thin Films IST alongside with Professor Dr. Günter Bräuer. At the same time, Prof. Herrmann will remain head of the TU Institute of Machine Tools and Production Technology IWF. Thus, the IST is now linked twice to the university as the Fraunhofer Institute is already connected to the Institute of Surface Technology IOT at the TU Braunschweig via Professor Bräuer, member of the management at the Fraunhofer IST.

1 *PhD students of the Fraunhofer IST and the Institute of Surface Technology of the TU Braunschweig at the second "Science Day".*

2 *Dr. Ralf Bandorf receiving the certificate of appointment for a Distinguished Chair Professorship at Feng Chia University (f.l.t.r.: Prof. Dr. Günter Bräuer, Prof. Bing-Jean Lee, Dr. Ralf Bandorf, Prof. Jin-Huang Huang).*

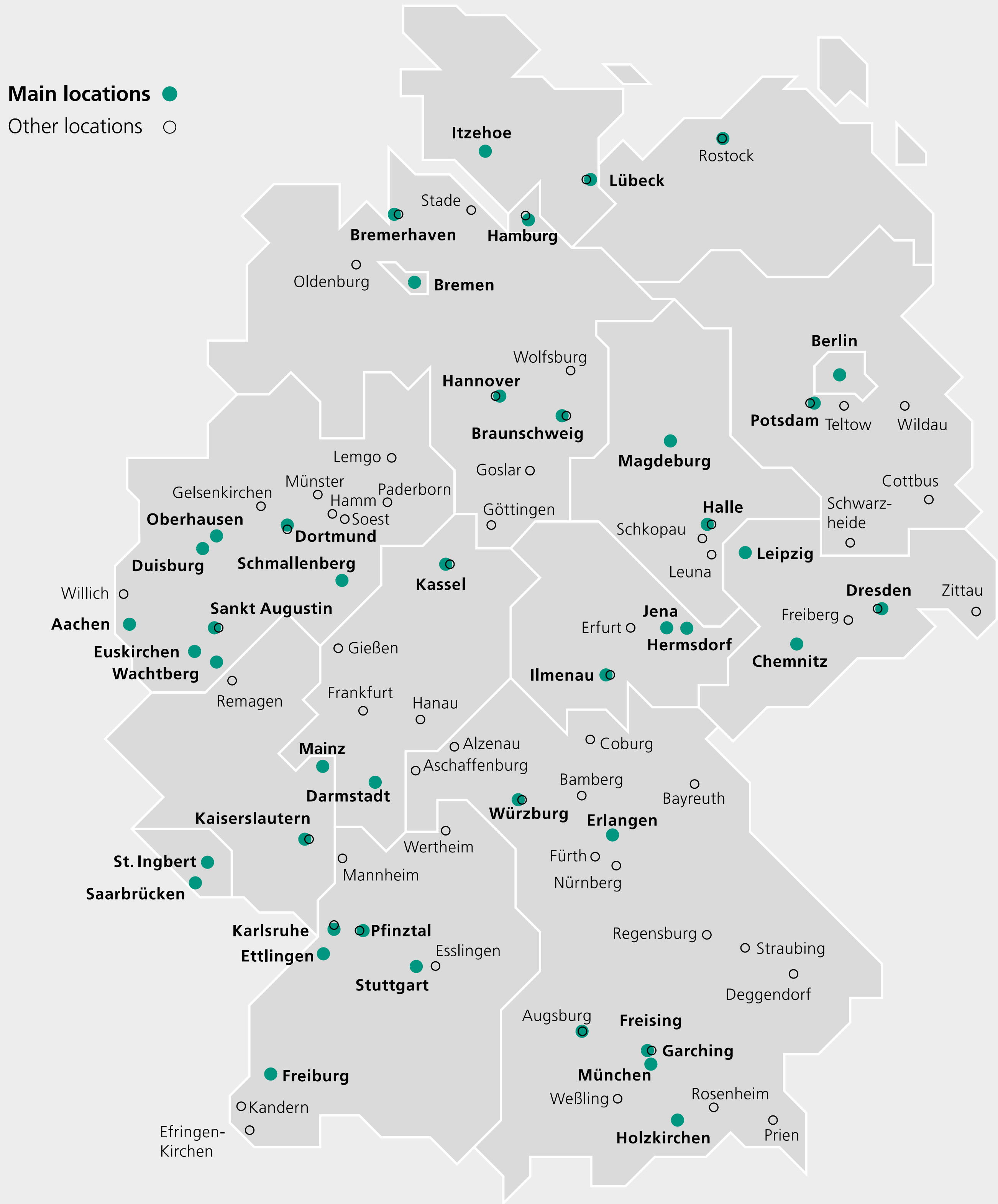
3 *The participants of the Science Campus at the Fraunhofer IST.*

4 *The institute management of the Fraunhofer IST, Professor Dr. Christoph Herrmann (right) and Professor Dr. Günter Bräuer.*

THE FRAUNHOFER IST IN NETWORKS

With its research and development activities, the Fraunhofer Institute for Surface Engineering and Thin Films IST is part of various internal and external networks which function with different points of emphasis in the field where business, science and politics interact and even clash. Within the Fraunhofer-Gesellschaft, the institute combines 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 looks out for future scientists and researchers. For this reason the institute networks intensively with educators, students and pupils in order to raise enthusiasm for the natural sciences and engineering at an early age and to encourage the upcoming generation of scientist.


Main locations
Other locations
Itzehoe
Rostock
Lübeck
Stade
Bremerhaven
Hamburg
Oldenburg
Bremen
Berlin
Wolfsburg
Hannover
Braunschweig
Potsdam
Teltow
Wildau
Magdeburg
Lemgo
Goslar
Cottbus
Gelsenkirchen
Münster
Paderborn
Hamm
Schwarz-
heide
Göttingen
Halle
Oberhausen
Soest
Schkopau
Dortmund
Leipzig
Duisburg
Schmallenberg
Kassel
Leuna
Willich
Dresden
Zittau
Sankt Augustin
Jena
Freiberg
Aachen
Erfurt
Hermsdorf
Euskirchen
Gießen
Chemnitz
Wachtberg
Ilmenau
Remagen
Frankfurt
Hanau
Alzenau
Coburg
Mainz
Aschaffenburg
Bamberg
Bayreuth
Darmstadt
Würzburg
Kaiserslautern
Erlangen
Wertheim
Fürth
St. Ingbert
Mannheim
Nürnberg
Saarbrücken
Karlsruhe
Pfinztal
Regensburg
Straubing
Esslingen
Ettlingen
Stuttgart
Deggendorf
Augsburg
Freising
Garching
Freiburg
München
Weßling
Rosenheim
Kandern
Prien
Efringen-
Kirchen
Holzkirchen

THE FRAUNHOFER-GESELLSCHAFT AT A GLANCE

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

At present, the Fraunhofer-Gesellschaft maintains 72 institutes and research units. The majority of the more than 26,600 staff are qualified scientists and engineers, who work with an annual research budget of more than 2.5 billion euros. Of this sum, more than 2.1 billion euros is generated through contract research. Around 70 percent of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Around 30 percent is contributed by the German federal and state governments in the form of base funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

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

With its clearly defined mission of application-oriented research and its focus on key technologies of relevance to the future, the Fraunhofer-Gesellschaft plays a prominent role in the German and European innovation process. Applied research has a knock-on effect that extends beyond the direct benefits perceived by the customer: Through their research and development work, the Fraunhofer Institutes help to 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.

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FRAUNHOFER GROUP LIGHT & SURFACES

Competence by Networking

Within the Fraunhofer Group for Light & Surfaces, six Fraunhofer institutes cooperate in the fields of lasers, optics, metrology and coating technology. Building on their basic research in the various fields of application, the institutes work together to supply fast, flexible and customer-specific system solutions in the fields of coating technology and photonics. Strategy is coordinated to reflect current market requirements, yielding synergies that benefit the customer. The institutes also collaborate with their local universities to provide the full range of student education, up to and including doctoral studies. As a result, the Fraunhofer institutes are not only partners to technological development, but also a continuous source of new talent in the fields of coating technology and photonics.

Core Competences of the Group

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

Fields of Application

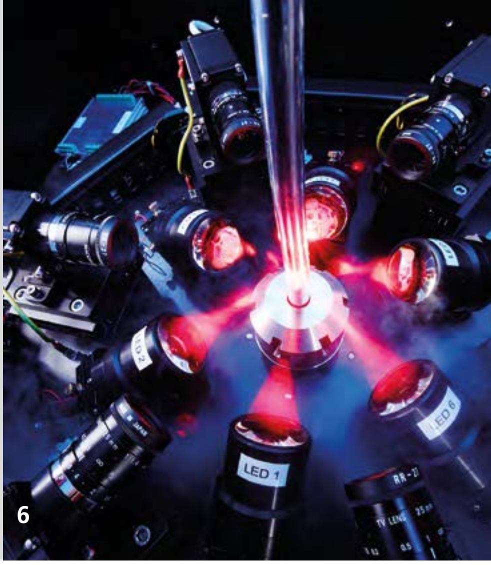
- Automotive
- Biotechnology and Life Science
- Electronics and Sensors
- Energy and Environment
- Aerospace
- Mechanical and Plant Engineering, Tool Making
- Optics

Fraunhofer Institute for Applied Optics and Precision Engineering IOF[2]

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

Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP[3]

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



Fraunhofer Institute for Laser Technology ILT[4]

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

Fraunhofer Institute for Surface Engineering and Thin Films IST[5]

The Fraunhofer Institute for Surface Engineering and Thin Films IST is an innovative partner for research and development in surface technology, with expertise in the associated product and production systems. The aim is to develop customized and sustainable solutions: from prototypes, through economic production scenarios, to upscaling to industrial magnitudes – and all this whilst maintaining closed material and substance cycles.
www.ist.fraunhofer.de

Fraunhofer Institute for Physical Measurement Techniques IPM[6]

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

Fraunhofer Institute for Material and Beam Technology IWS[1]

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

CONTACT

GROUP CHAIRMAN
Prof. Dr. Reinhard Poprawe
reinhart.poprawe@ilt.fraunhofer.de

GENERAL MANAGER
Dr.-Ing. Arnold Gillner
Phone +49 241 8906-148
arnold.gillner@ilt.fraunhofer.de

www.light-and-surfaces.fraunhofer.de

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SUPPORTING AND TRAINING YOUNG SCIENTISTS AT THE FRAUNHOFER IST

Youth development – for the Fraunhofer Institute for Surface Engineering and Thin Films IST this means being active not only as a trainer and in an university setting, but also to introduce young people to scientific topics, to take away their reservations and to attract them to industry-related research. The promotion and supervision of pupils and students who are interested in the research activities of the Fraunhofer IST, was again an important part of the institutes work in the year 2018.

Visit by the jDPG (Young German Physical Society)

Braunschweig, 10th April 2018. Within the framework of an excursion to the research location Braunschweig, 21 members of the Young DPG Working Group visited the Fraunhofer IST this year. Following a presentation of the Institute by Prof. Günter Bräuer, Institute Director, the students were introduced to the subject of layer and surface technology, with the center of interest focused on physical topics. During the subsequent guided tour of the institute, the young scientists were able to obtain their own impressions of the activities at the Fraunhofer IST.

Future Day for girls and boys at the Fraunhofer IST

Braunschweig, 26th April 2018. This year, the Fraunhofer IST, together with the Fraunhofer WKI, once again opened its doors in order to encourage school pupils to take an interest in science within the framework of "Future Day for Girls and Boys". A total of 22 young researchers – 11 girls and 11 boys – immersed themselves into the fascinating day-to-day research work at the Fraunhofer institutes for one day.

Equipped with lab coats and protective goggles, the pupils passed large coating facilities and yellow rooms on their way through the laboratories of the two institutes. During diverse experiments and hands-on activities at the Fraunhofer IST, the pupils were given an insight into the world of thin films and were allowed to pre-treat plastic cars with atmospheric-pressure plasmas and subsequently metallize them without electricity using copper. At the end of the day, the girls and boys were able to take their coated works home as souvenirs – thus, perhaps one or two scientific sparks were thereby ignited.

Visit by the Kranich-Gymnasium Salzgitter

Braunschweig, 14th June 2018. This year, pupils from the Kranich-Gymnasium (Kranich high school) in Salzgitter visited the Fraunhofer IST for the very first time within the framework of a specialized seminar course on the problem of the water situation in the 21st century. Accordingly, the young people's interest focused particularly on the activities of the Fraunhofer IST in the field of the development of sustainable system solutions for water supply, water infrastructures and waste water treatment.

1 *The members of the jDPG during their visit to the Fraunhofer IST as part of their excursion to the research site Braunschweig.*

2 *Two participants of the "Future Day" are currentless copperplating atmospheric plasma pre-treated plastic cars.*

3 *Sven Pleger, trainer at the Fraunhofer IST, introduces electrochemical systems with diamond electrodes for water purification to the pupils of the Kranich-Gymnasium.*

Following a presentation of the Fraunhofer IST, the professions in the MINT field (mathematics, computer science, natural sciences and technology), and training opportunities at the IST, the 11th grade pupils were able to visit laboratories in which the development of electrochemical systems with diamond electrodes for water purification is carried out.

Pupil internship at the Fraunhofer IST

Inline with the motto "research needs young talents", the Fraunhofer IST once again offered internships for school pupils this year. Over a period of three weeks, two female and seven male pupils became familiar with the everyday life of a physics laboratory assistant at the Fraunhofer IST.

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

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

The objective of the network is to make plasma engineering better known and to support, promote, and accompany development in the numerous application areas in their respective complexity. Several highlights of the many activities, projects, and events in 2018 are presented in the section below:

13th INPLAS General Meeting at Miele & Cie. KG

The 13th INPLAS General Meeting was held on 14th November 2018 at Miele & Cie. KG in Oelde. The Meeting is an important gathering for the members at which they can discuss future network activities. The opinions of the members are thereby included and the exchange of ideas is encouraged. Specialist topics were discussed which form the focus of the various working groups. The topic "Plasma Technology 4.0 – Digitization and Big Data" thereby played a key role. A factory tour provided the participants with an interesting insight into production at Miele.

INPLAS working groups

The working group "Innovative Plasma Sources and Processes" with the management team of Dr. Ulf Seyfert from Von Ardenne, Matthias Nestler from scia systems GmbH and Dr. Anke Hellmich, Applied Materials met in April at TRUMPF in Ditzingen. The second meeting in November took place following the General Meeting in Oelde. Topics of the year were Industry 4.0 in the field of plasma technology, and PECVD processes.

The WG "Tool Coatings", under the direction of Hanno Paschke, DOC, Fraunhofer IST, met at the IWF in Berlin in March and at the Fraunhofer IST in Braunschweig in November. The topics were the current "ÖkoClean" project, the preparation of a project outline on the subject of digitization and big data and various new project approaches in the area of machining.

Members of both working groups met in Braunschweig in September for a brainstorming meeting on the topic of "Plasma Technology 4.0" to discuss the goals, opportunities and challenges of "Digitization and Big Data". It quickly became clear that the demand was high and that still many unanswered questions required clarification. The first points of discussion included, amongst others, the definition of terms, application-specific questions, data protection and interfaces. Furthermore, technical tasks such as workpiece tracking, data selection, data reliability and interface standards, were discussed. Using the results, the administrative office developed a questionnaire with the aim to show the differences in fields of application approach the topics of parameter recording, data storage and processing and what can be learned from other groups who are addressing the measurement of parameters. At the next WG meeting in May 2019, evaluations will be presented and the discussions will be continued.

In the Community Committee "Combined Surface Technology" at the Leibniz Institute of Polymer Research Dresden, the topics were Additive Manufacturing and Polymer Layers.

The WG “Plasma4Life” met in April at the Fraunhofer ITEM in Hanover and in October at Lionex in Braunschweig. The topics were hygiene, sterilization and biomedicine.

39th Meeting of the industry working group (IAK) “Tool Coatings and Cutting Materials“

With more than 40 participants, the IAK is a popular forum for the exchange of insights and information with regard to the latest trends of tool manufacturers and users. The meeting takes place twice a year in Berlin and Braunschweig with partners from the IWF of the TU Berlin, the Fraunhofer IPK, the Fraunhofer IST, and INPLAS e. V. On 8th November, the focus in Braunschweig was directed on topics such as materials which are difficult to machine, digitization, new measuring methods for cyclic material behavior, and surface qualities in wire production.

INPLAS joint stand at the Conference on Plasma Surface Engineering – PSE

The 16th International Conference on Plasma Surface Engineering, PSE 2018, took place in Garmisch-Partenkirchen from 16th to 21st September 2018. Within the framework of the industrial exhibition, the following members presented themselves on the INPLAS joint stand: Advanced Energy Industries GmbH, CCR Technology, C4E Technology GmbH, Fraunhofer FEP, Fraunhofer IST, Singulus Technolgies AG, W & L Coating Systems GmbH, IOT TU Braunschweig.

Partial listing of other public relations projects or service projects

- Training Q-Plas: The E-Learning portal and practical apprenticeships: www.q-plas.de
- Plasma Germany: meetings and workshops
- Dissemination of the EU projects: FAST, SafeWaterAfrica

1 *INPLAS members (Status: November 2018).*

2 *Working group meeting at Lionex GmbH (Photo: Ilka Blumentritt).*

CONTACT

Dipl.-Ing. Carola Brand
Managing Director
Phone +49 531 2155-574
carola.brand@inplas.de

Dr. Jochen Borris
Dipl. Des. Ilka Blumentritt

www.inplas.de

PUBLICATIONS

Memberships

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

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

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

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

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

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

Europäische Forschungsgesellschaft für Blechverarbeitung e.V. (EFB)
www.efb.de

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

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

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

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

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

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

Fraunhofer-Allianz Adaptronik
www.adaptronik.fraunhofer.de

Fraunhofer-Allianz autoMOBILproduktion
www.automobil.fraunhofer.de

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

Fraunhofer-Allianz Leichtbau
www.leichtbau.fraunhofer.de

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

Fraunhofer-Allianz Reinigungstechnik
www.allianz-reinigungstechnik.de

Fraunhofer-Allianz Space
www.space.fraunhofer.de

Fraunhofer-Allianz SysWasser
www.syswasser.de

Fraunhofer-Allianz Textil
www.textil.fraunhofer.de

Fraunhofer-Netzwerk Elektrochemie
www.elektrochemie.fraunhofer.de

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

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

German Flatpanel Display Forum DFF
www.displayforum.de

German Water Partnership
www.germanwaterpartnership.de

Göttinger Research Council
www.uni-goettingen.de

Innovationsnetzwerk Niedersachsen
www.innovationsnetzwerk-niedersachsen.de

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

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

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

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

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

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

Optence e.V.
www.optence.de

PhotonicNet GmbH – Kompetenznetz Optische Technologien
www.photonicnet.de

Plasma Germany
www.plasmagermany.org

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

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

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

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

Board memberships

Abraham, T.: Fachausschuss FA 10 "Funktionelle Schichten" der Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik e. V. AWT, Mitglied.

Bandorf, R.: Europäische Forschungsgesellschaft Dünne Schichten e. V. (EFDS), Beirat.

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

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

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

Bandorf, R.: Society of Vacuum Coaters, Member Board of Directors.

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

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

Brand, C.: Arbeitgeberverband Region Braunschweig, Mitglied.

Brand, C.: Europäische Forschungsgesellschaft Dünne Schichten e. V. (EFDS), Mitglied.

Brand, C.: Kompetenznetz Industrielle Plasma-Oberflächentechnik INPLAS e. V., Geschäftsführerin.

Brand, C.: Plasma Germany, Mitglied des Koordinierungsausschusses.

Brand, J.: Gesellschaft für Tribologie (GfT), Mitglied.

Brand, J.: International Colloquium Tribology, Tribology and Lubrication Engineering, Mitglied im Programme Planning Committee.

Bräuer, G.: European Joint Committee on Plasma and Ion Surface Engineering (EJC / PISE), Chairman.

Bräuer, G.: International Conference on Coatings on Glass and Plastics (ICCG), Vorsitzender des Organisationskomitees.

Bräuer, G.: International Council for Coatings on Glass (ICCG) e. V., Mitglied des Vorstands.

Bräuer, G.: Institut für Solarenergieforschung, Mitglied des Beirats.

Bräuer, G.: Kompetenznetz Industrielle Plasma-Oberflächentechnik INPLAS e. V., Vorstandsvorsitzender.

Bräuer, G.: Zeitschrift "Vakuum in Forschung und Praxis", Mitglied des Kuratoriums.

Bräuer, G.: Zentrum für Mikroproduktionstechnik e. V., Mitglied des Vorstands.

Dietz, A.: Arbeitsgemeinschaft Elektrochemischer Forschung (AGEF), Mitglied.

Dietz, A.: Deutsche Gesellschaft für Galvano- und Oberflächentechnik e. V. (DGO), Mitglied des Vorstands.

Dietz, A.: Deutsche Gesellschaft für Galvano- und Oberflächentechnik e. V. (DGO), stellvertretender Vorsitzender Ortsgruppe Niedersachsen.

Dietz, A.: Fachausschuss "Forschung" der DGO, Mitglied.

Dietz, A.: Fachausschuss "Kombinationsschichten" der DGO, Mitglied.

Eichler, M.: Conference on Wafer Bonding for Microsystems 3D- and Wafer Level Integration, Steering Committee.

Eichler, M.: Plasma Surfaces in Healthcare and Industry, International Scientific Committee, Host.

Gäbler, J.: DIN Deutsches Institut für Normung e. V., Normenausschuss 062 Materialprüfung, Arbeitsausschuss 01-72 "Chemische und elektrochemische Überzüge", Mitglied.

Gäbler, J.: DIN Deutsches Institut für Normung e. V., Normenausschuss NA 062 Materialprüfung, Arbeitsausschuss NA 062-01-64 AA Arbeitsausschuss Kohlenstoffschichten, stellvertretender Obmann.

Gäbler, J.: European Technology Platform for Advanced Materials and Technologies EuMaT, Mitglied.

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

Gäbler, J.: ISO Technical Committee TC 107 "Metallic and other inorganic coatings", P-Member.

Gäbler, J.: VDI-Richtlinien-Fachausschuss "CVD-Diamant-Werkzeuge", Mitglied.

Gerdes, H.: International Conference on Metallurgical Coatings and Thin Films, Session Chairman.

Gerdes, H.: Society of Vacuum Coaters, Dozent.

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

Gerdes, H.: VDI/VDE-GMA Fachausschuss 2.11 "Elektrische Messverfahren; DMS-Messtechnik", Mitglied.

Keunecke, M.: EFDS-Fachausschuss "Tribologische Schichten", Mitglied.

Keunecke, M.: OTTI-Fachforum PVD- und CVD-Beschichtungsverfahren für tribologische Systeme, Fachliche Leitung.

Keunecke, M.: SAE International, Mitglied.

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

Keunecke, M.: Society of Vacuum Coaters, Session Chairman.

Klages, C.-P.: Europäische Forschungsgesellschaft Dünne Schichten e. V. (EFDS), Mitglied des wissenschaftlichen Beirats.

Lachmann, K.: COST Action MP1101 "Biomedical Applications of Atmospheric Pressure Plasma Technology", Management Committee, Substitute.

Neumann, F.: DIN Deutsches Institut für Normung e. V., Normenausschuss 062 Materialprüfung, Arbeitsausschuss NA 062-02-93 AA "Photokatalyse", Leitung des Arbeitskreises "Photokatalytische Selbstreinigung".

Neumann, F.: Europäisches Komitee für Normung, CEN/TC 386 "Photocatalysis", Delegierter des Technischen Komitees.

Neumann, F.: Europäisches Komitee für Normung, CEN/TC 386 "Photocatalysis", Mitglied.

Neumann, F.: Fachverband Angewandte Photokatalyse (FAP), Forschungsausschuss, Mitglied.

Neumann, F.: Ostfalia Hochschule für angewandte Wissenschaften, Fakultät Versorgungstechnik, Studiengang "Bio- und Umwelttechnik", Mitglied des Beirats.

Neumann, F.: ISO Normenausschuss TC 206/WG 9 "Photocatalysis", Mitglied.

Paschke, H.: Fachausschuss FA10 "Funktionelle Schichten" der Arbeitsgemeinschaft Wärmebehandlung und Werkstofftechnik e. V. AWT, Mitglied.

Paschke, H.: Industrie-Arbeitskreis "Werkzeugbeschichtungen und Schneidstoffe", Leitung.

Paschke, H.: Kompetenznetzwerk für Oberflächentechnik "netzwerk-surface.net", wissenschaftlicher Beirat (Sprecher).

Paschke, H.: Kompetenznetz Industrielle Plasma-Oberflächentechnik INPLAS e. V., Arbeitsgruppenleiter Werkzeugbeschichtungen.

Schäfer, L.: Beirat der CONDIAS GmbH, Mitglied.

Schäfer, L.: Industriearbeitskreis "Werkzeugbeschichtungen und Schneidstoffe", Mitglied.

Schäfer, L.: Nanotechnologie-Kompetenzzentrum Ultrapräzise Oberflächenbearbeitung CC UPOB e. V., Mitglied.

Schäfer, L.: VDI-Richtlinien-Fachausschuss "CVD-Diamant-Werkzeuge", Mitglied.

Sittinger, V.: Europäische Forschungsgesellschaft Dünne Schichten e. V. (EFDS), Workshop "Dünnschichttechnologie für Energiesysteme, V2017", Chairman, Programmkomitee.

Sittinger, V.: European Photovoltaic Solar Energy Conference and Exhibition, Scientific Committee, Paper Review Expert.

Sittinger, V.: Society of Vacuum Coaters, Session Chairman.

Stein, C.: Society of Vacuum Coaters, Dozent.

Stein, C.: Society of Vacuum Coaters, Session Chairman.

Stein, C.: VDI-Arbeitskreis "Schneidstoffanwendungen", Mitglied.

Thomas, M.: Anwenderkreis Atmosphärendruckplasma (AK-ADP), Mitglied.

Thomas, M.: Arbeitsgruppe "Plasma4Life" INPLAS e.V., Mitglied.

Thomas, M.: DECHEMA – Gesellschaft für Chemische Technik und Biotechnologie e. V., Mitglied.

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

Thomas, M.: Plasma Surfaces in Healthcare and Industry, International Scientific Committee.

Thomas, M.: International Conference on Plasma Surface Engineering, International Program Committee IPC, Mitglied.

Thomas, M.: International Conference on Plasma Surface Engineering, Session Chairman.

Thomas, M.: European Joint Committee on Plasma and Ion Surface Engineering (EJC / PISE).

Vergöhl, M.: Europäische Forschungsvereinigung für dünne Schichten e.V. (EFDS), Mitglied des Vorstands.

Vergöhl, M.: Europäische Forschungsvereinigung für dünne Schichten e.V. (EFDS), stellvertretende Leitung des Fachausschusses "Beschichtungstechnologien für optische und elektronische Funktionalisierung".

Vergöhl, M.: Lenkungskreis "Photonik" des VDMA, Mitglied.

Vergöhl, M.: Optical Society (OSA), Dozent.

Viöl, W.: Amt für regionale Landesentwicklung Braunschweig, Mitglied Fachbeirat Südniedersachsen.

Viöl, W.: Bundesministerium für Bildung und Forschung BMBF, Mitglied des Programmbeirats.

Viöl, W.: Deutsche Gesellschaft für Plasmatechnologie e. V. DGPT, Mitglied des Vorstands.

Viöl, W.: DFG Fachkollegien, Mitglied.

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

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

Viöl, W.: Hochschulrektorenkonferenz Forschungskommission Fachhochschulen.

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

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

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

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

Publications

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Rieke, J.; Gerdes H.; Bandorf, R.; Schütte, T.; Bräuer, G.: Controlling stoichiometry and ionization of reactive HIPIMS processes by using plasma emission monitoring, 61th Annual Technical Conference of Society of Vacuum Coaters SVC, Orlando, Florida, USA, 5. – 10. Mai 2018 (Lecture).

Schiffmann, K. I.: SIMS Analyse tribologischer Schichten - Quantitative Bestimmung von H in DLC und Cr in CrN-Schichten auf gekrümmten Oberflächen: Einfluss des Einfalls- und Abnahmewinkels, 20. Arbeitstagung Angewandte Oberflächenanalytik (AOFA 20), Kaiserslautern, 3. – 5. September 2018 (Poster).

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Bröcker, Lars: PECVD-Abscheidung von stickstoff- und sauerstoffhaltigen diamantähnlichen Kohlenstoffschichten für den Einsatz als Antifouling-Beschichtung, Technische Universität Braunschweig, 2018.

Charfi, Hela: Optimierung der Härteprüfung an Zahnstangen, Technische Universität Braunschweig, 2018.

Dittrich, Fabian: Numerische Strömungsdynamik und aquatisch-chemische Modellierung des Loskop Dam Stausees, Technische Universität Braunschweig, 2018.

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Schudack, Lisa Kristina: Einflussnahme der Materialschädigung durch Regenerosion auf einen potentiellen Eisansatz an beschichteten GFK-Proben der Rotorblätter von Windenergieanlagen, Technische Universität Braunschweig, 2018.

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Märtins, David: Einfluss des verwendeten Abscheideverfahrens auf die Eigenschaften von gesputterten Kohlenstoffschichten, Technische Universität Braunschweig, 2018.

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Britze, Chris: Entwicklung eines Strahlenteilers mit geringem Wellenfrontfehler, Braunschweig, 2018.

Lips, Julian: Gravimetrische Vermessung der Derivatisierung von Aminogruppen mittels 4-Trifluoromethylbenzaldehyde (TFBA). Braunschweig, 2018.

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Ortner, K.; Stephan, M.: Dental article with a coating comprising nanostructures made of yttria-stabilized zirconia.

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Fraunhofer Institute for Surface Engineering
and Thin Films IST

Director of the Institute
Prof. Dr. Günter Bräuer
Prof. Dr.-Ing. Christoph Herrmann

Deputy Director of the Institute
Dr. Lothar Schäfer

Bienroder Weg 54 E
38108 Braunschweig, Germany
Phone +49 531 2155-0
Fax +49 531 2155-900
info@ist.fraunhofer.de
www.ist.fraunhofer.de

Editorial and Coordination
Dr. Simone Kondruweit
Sandra Yoshizawa

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