Fraunhofer Institut Elektronenstrahl- und Plasmatechnik

Annual Report 2006

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treatment with electron beams

Innovation by FEP

Annual Report 2006

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Foreword

Dear Sir or Madam,

we hope this 2006 annual report of the Fraunhofer Institute for Electron Beam and Plasma Technology will once again give you an interesting insight into our work activities.

In the summer of 2006 we joined the "exclusive club". The INPLAS (INdustrial PLASma surface technology) network, which we founded in the autumn of 2005, was accredited in June by the "German Expertise Network" of the Federal Ministry of Economics and Technology. The INPLAS network currently has 18 members and this number will further increase in 2007. The accreditation was a noteworthy event in a very successful year for the Fraunhofer FEP. Dresden had the honor of being "City of Science 2006" and numerous events were organized. The "Day of Technology" on 30th June attracted several thousand visitors to the Fraunhofer Institute Center. Fascinating exhibits and experiments enabled the visitors to discover and experience science and technology for themselves at first hand. One of the highlights was the show of the "physics technicians" who surprised the public with spectacular experiments involving physics and chemistry.

In June the 6th International Conference on Coatings on Glass and Plastics was held in Dresden. The PR group at the FEP were responsible for the local organization of this conference. Some 500 delegates and 38 industrial exhibitors took part, which marked a record for the conference. In addition to the much-praised scientific-technical conference program the high number of delegates can also be attributed to the special attraction of Dresden as the venue. You will find further details on the conference in this annual report.

A further highlight of the past year, was not only the 800th anniversary of the city Dresden but also for the FEP the reopening of the Green Vault Museum. The baroque wall mirrors in the jewel room were reconstructed with the help of modern sputtering technology at the Fraunhofer FEP.

From a fiscal standpoint 2006 was the most successful year in our institute's short history. External funding increased from 6.9 million euros in 2005 to 9.5 million euros in 2006. Funding from industry represented 44% of the total funding. This positive development is continuing into 2007 with most of the necessary external funding having already been assured.

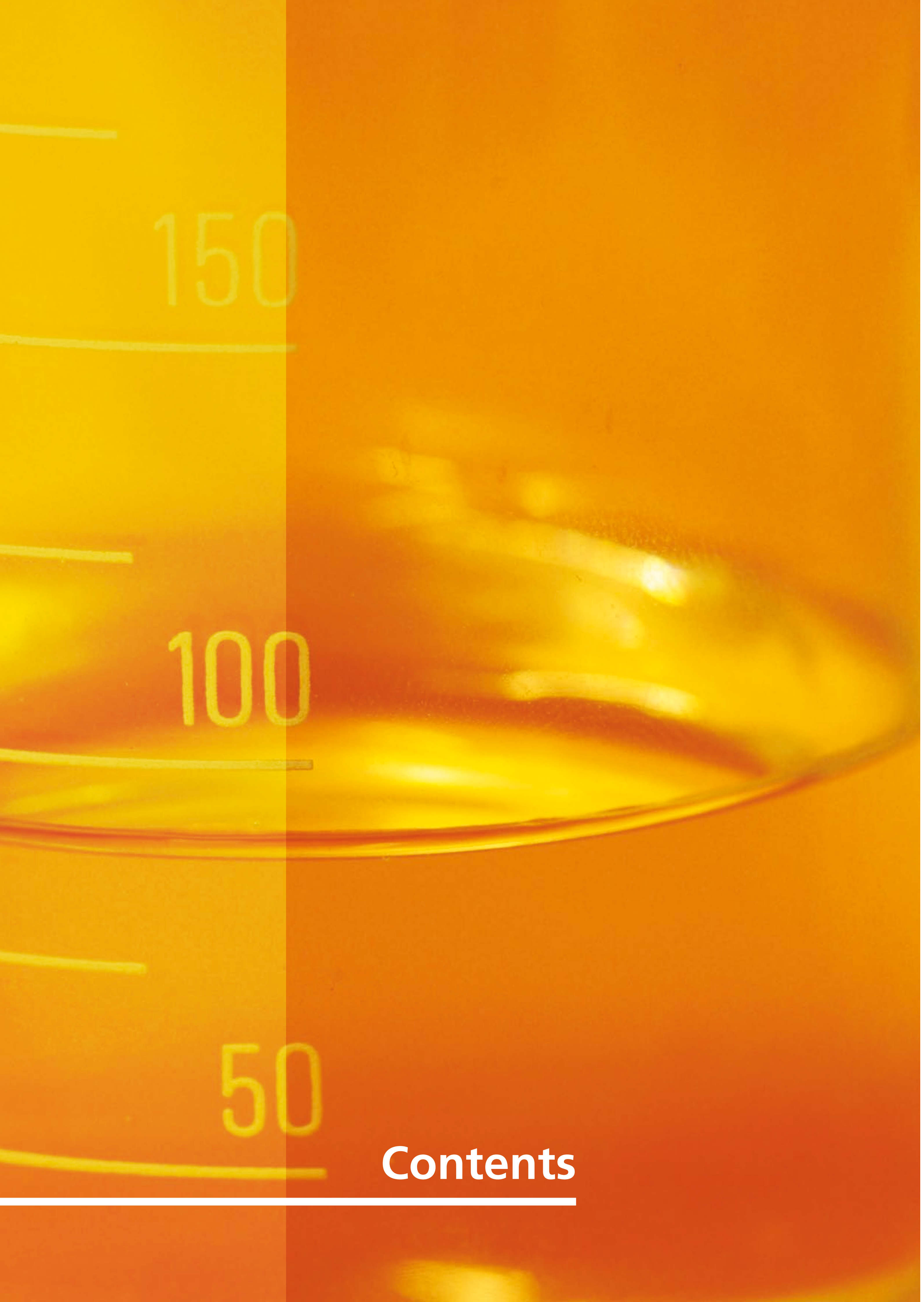
In 2006 there were promising developments at the scientific-technical level which keep the FEP well placed for the future. Novel beam sources based on plasma discharges mean there is a renaissance in electron beam technology, with significant cost advantages compared to conventional sources. The treatment of surfaces with non-thermal electrons is being used in new application areas and after many years of collaboration with a major manufacturer of packaging films we received the first commission for a plant for manufacturing transparent barriers using plasma-activated high-rate evaporation. The link between the FEP and the Technical University of Dresden has been successful, as deemed by the growing audiences at lectures. In particular the lecture on electron beam technology, a unique event in Germany which made a contribution to the renaissance of this field in the material sciences, proved highly interesting to physicists, machine constructors and electrical engineers in the audience.

Finally, we would like to extend our thanks to our industrial partners, R&D partners and funding organizations. Your trust in us and your support are major factors that have contributed to the success of our institute. Naturally the performance of the FEP staff has played an absolutely crucial role this past year and we would like to thank all FEP employees here for their sterling work.

Prof. Dr. Günter Bräuer

Prof. Dr. Eberhard Schultheiß

Prof. Dr. Volker Kirchhoff



Contents

Board of Trustees

Our Board of Trustees

Annually the members of our board of trustees, which consists of representatives of economy, science and public life, get together at the FEP. Within this meeting current themes referring our work, the planning and strategies of our institute are being presented and discussed.

The members of our board of trustees do contribute with their extensive experience and recent market knowledge to the constitution of current and future business fields.

As follows we would like to introduce our board of trustees.

Our Board of Trustees

The Institute

Profile of the Fraunhofer FEP

The Fraunhofer Institute for Electron Beam and Plasma Technology (FEP) Dresden is one of 58 institutes belonging to the Fraunhofer-Gesellschaft. Following the German reunion it was established by working groups of the former Manfred von Ardenne R&D institute in Dresden. Since then in the FEP technologies are being invented, tested and improved for industrial applicability. In cooperation with our proficient partners we are able to provide adequate process technology as well as the appropriate engineering systems according to the scope of our clients. This is leading us to the status of being a partner for satisfied clients all over the world.

One of the Fraunhofer FEP´s main fields of activity is the thin film technology. This includes coating of sheets, strips and components made of diverse materials with various layers or layer systems. This field serves a diversified, world wide market. Many items of our daily life are equipped with adapted layer qualities. Highly productive plants are producing layers on millions of square metres of plastic films, glass, other synthetic materials or metal. Plastic web for packaging gain aroma density through special barrier layers. Metal sheets which can be used for facade cladding are being valorised by corrosion protective and decorative layers. Sun protection foils or heat-insulating architectural glass follow the application of light filtering layer systems.
Furthermore the applied research work of the FEP is responsible for special layers as used for displays, forgery-proof labels or for the mirrors in the newly restored Green Vault in Dresden beneath many other products. The second main field of activity of the FEP is the electron beam technology. The electron beam is being used for the welding and evaporation of metals as well as for the modification in edge layers.
Further applications are the curing of lacquers, the improvement of plastics properties, the sterilization of medical devices and the germ reduction of seed and grain. Electron beams are used as a precise tool containing a large reach of efficiency within a diversified field of applications. Many of those developments are closely correlated with the fields of electrical engineering, electronics as well as microelectronics. Numerous innovative products, for example thin film solar cells, sensors, microelectronic components or data media are being produced by means of technologies developed by the FEP. For this kind of research we increased the cooperation with Saxon universities and technical colleges during the last few years. The main focus of this team work lies on the organisation of a purposeful education and training in the FEP related technology fields.

As an industry-related R&D centre the Fraunhofer Institute for Electron Beam and Plasma Technology (FEP) sets itself the task to offer innovative and custom-tailored solutions in the field of thin film and surface technology. These solutions may be highly sophisticated as they contain the selection of a functional optimised layer system beneath the development of appropriate cleaning or pre-treatment solutions for the substrate. Further services are the development and optimisation of coating source and coating process, the up-scaling to a product adapted measure as well as the technology transfer to laboratory and production plants and the integration into the production process. At the same time economic considerations of the process development play an outstanding role. The cost effectiveness of the total system has the highest priority. The generation of such optimal solutions demands the research and development of innovative processes by means of high density plasma and high performance electron beams. According to the key character of the layer and surface technology the FEP addresses a wide clientele. The most important branches are the building industry, transport sector, information technology, engineering, manufacturing industry, medicine and renewable energies.

Business fields and core competences

The Fraunhofer FEP comprises six business fields:

- Coating of flat substrates with optical layers and layer systems
- Coating of flexible products
- Coating of sheets and metal strips
- Surface modification and treatment with electron beam
- Coating of components
- Coating of components with optic, electronic and magnetic properties

Profile of the Fraunhofer FEP

The treatment of these business fields demands the following three core competences:

- Electron beam technology
- Pulse magnetron sputtering
- Plasma activated high rate deposition

These technologies are being used within the six business fields.

For the FEP a considerable part of new technologies is the development of new innovative key components for the surface technology that are being offered to the customer together with the according process technology as so called "technology packages".

In 2006 the institute employed 98 permanent employees (containing 57 scientists and 31 technical staff and 10 administrative staff/secretariat) as well as another 64 doctoral students, graduants, students and 10 trainees.

The Fraunhofer FEP disposes of 7000 m² laboratory area at two sites (Dresden and Helmsdorf). The equipment contains numerous industry-relevant plants for coating of plastic web, glass substrates, plastic sheets, metal strips and sheets or components using plasma activated high rate deposition and pulse magnetron sputtering. Three more plants are being used for welding and curing as well as the surface treatments via electron beams. Furthermore the institute holds several plants and a variety of analytical equipment for the characterization of surfaces and layers.

Therewith the FEP accomplishes the best conditions to make their innovations useful for the future of their clients.

Organizational Structure

General Management
from right to left

Prof. Dr. Günter Bräuer
Director

Prof. Dr. Eberhard Schultheiß
Member of Board

Prof. Dr. Volker Kirchhoff
Deputy Director / Division Plasma

Public Relations
Mrs. Annett Arnold

Protective Rights
Mr. Jörg Kubusch

Division Electron Beam E-processes
Mr. Rainer Bartel

Coating of sheets and metal strips
Dr. Christoph Metzner

Coating of flexible products
Dr. Nicolas Schiller

Coating of flat substrates
Dr. Torsten Kopte

Characterization / Analysis
Dr. Olaf Zywitzki

Coating of components
Dr. Heidrun Klostermann

Division Systems / Administration
Mr. Matthias Wünsche

Mr. Dieter Weiske
Mechanic Development

Mr. Dieter Leffler
Electronic Development

Mr. Rainer Zeibe
Workshop

Mr. Steffen Kaufmann
Outsourcing

Mr. Veit Mittag
Project Management

Mrs. Claudia Rockstroh
Purchasing

Mr. Roberto Wenzel
Information Technology

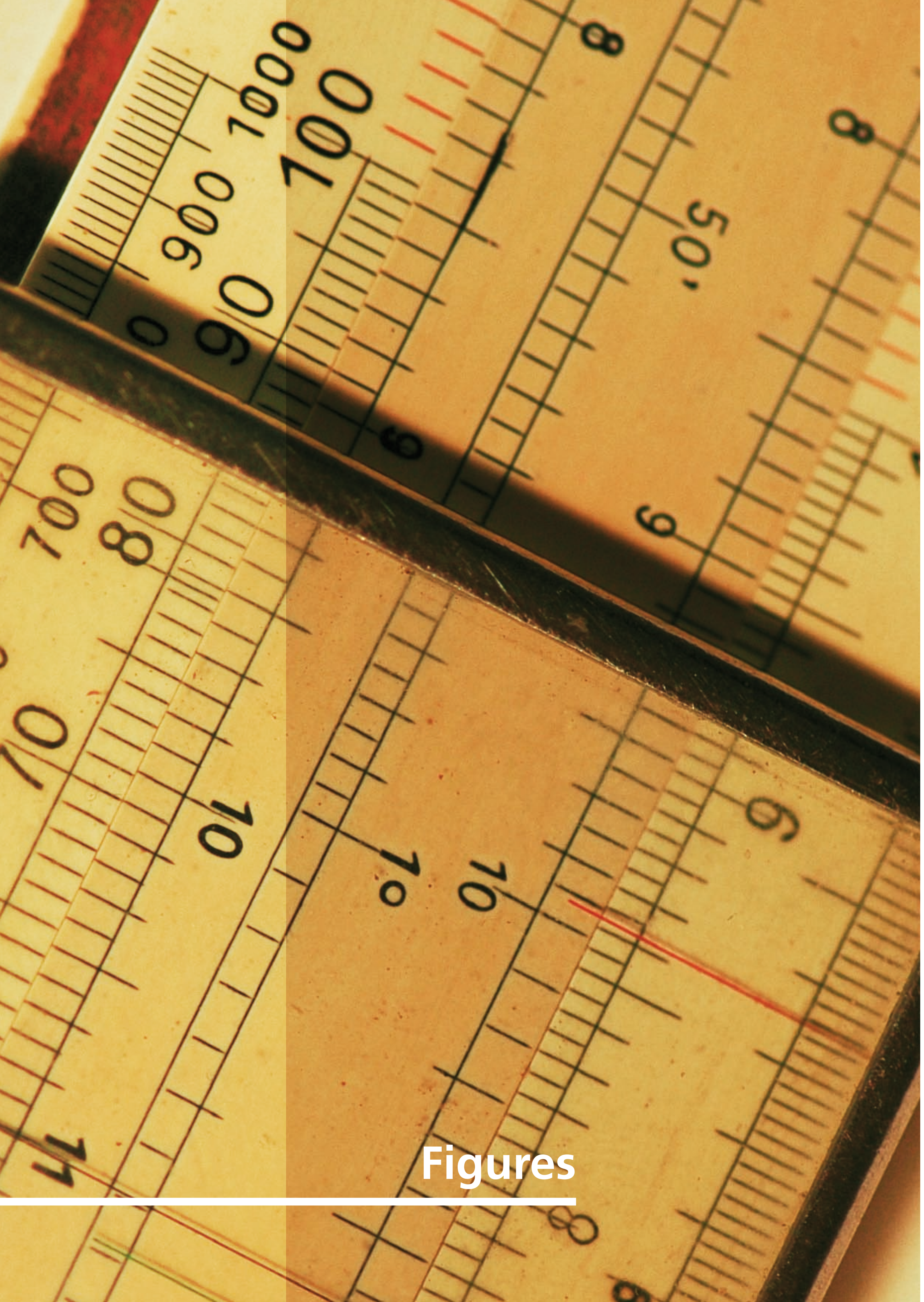
Mr. Wolfgang Nedon
Technical Management

Mr. Roman Nyderle
Group Manager Process Development

Dr. Ullrich Hartung
Group Manager Layer Development

Dr. Fred Fietzke
Group Manager
Machine Parts and Tools

Dr. Peter Frach
Group Manager Optic, Electronic and Magnetic Components



The Institute in Figures

Funding

The provisional operating results reflect a very promising year for the FEP. External funding increased by 39% compared to the previous year. This was mainly due to increased contract research with industry, represented by an increase of 44% to 6.2 million euros. There was, however, also an increase in contract research funded by the federal government and Länder, represented by 37% to 2.8 million euros. The majority of these projects were carried out in collaboration with medium-sized companies and the Saxon Ministry for Trade, Industry and Employment.

External funding (in millions of euros) in the report year was split as follows:

Income from industry (contract research with industry)	6.2
Public income (contract research funded by the federal government and Länder)	2.8
Projects funded by the EU	0.1
Income from other organizations	0.4

in million euros

With total expenditure of 11.9 million euros, this meant that self-funding amounted to 80% of the budget. Employee costs amounted to 5.3 million euros. Material costs amounted to 5.9 million euros. In the report year 0.7 million euros were spent and 0.1 million euros on strategic investment for expanding our scientific and technical equipment and facilities in order to carry out our project work.

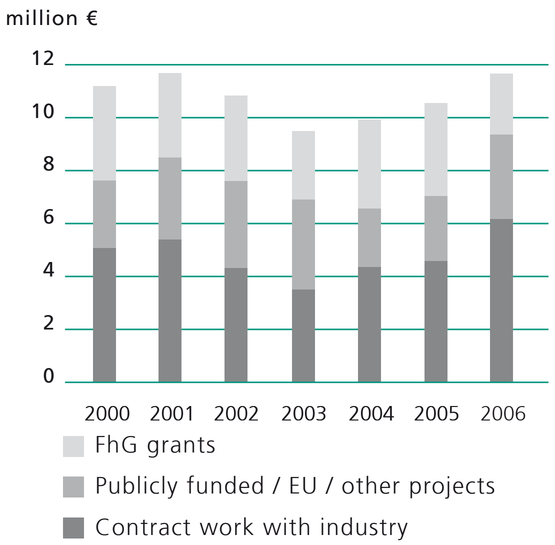
The Institute in Figures

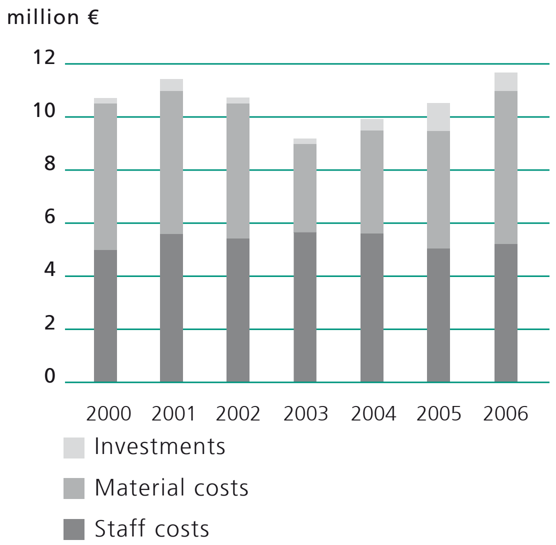
Workforce

At the end of the report year the FEP had a total of 98 permanent employees, of which 57 were scientists and engineers. Females made up 16% of the FEP workforce. As in previous years we strived to employ young, highly motivated graduate scientists and engineers for our research activities.
We successfully recruited 4 new graduates, so meeting our workforce requirements. The training of young technical staff by the FEP has special importance for our research activities and we undertake this training ourselves.

In the reporting period there were 2 physics laboratory technicians, 1 material tester and 2 students, studying respectively business science and informatics-media production at the Berufsakademie Dresden, in the process of being trained. For the coming year three further trainee technicians (for the physics laboratory, metal-working and precision engineering) have already been selected.

We would like to extend our thanks to all personnel and organizations involved in training our trainees.





	million €	million €
Expenditure		
Staff costs	5.3	
Material costs	5.9	
Investments	0.7	
Income		
External income		**9.5**
Contracts with industry		6.2
Publicly funded / EU / other projects		3.3
FhG grants		**2.4**
Total	**11.9**	**11.9**

Expenditure and income in 2006.

	Number
Scientists and engineers	57
Technicians	31
Administrative staff/secretariat	10
	98
Postgraduates	6
Undergraduates	8
Trainees	10
Students	50

FEP Workforce 2006.

Fraunhofer-Gesellschaft

The Fraunhofer-Gesellschaft

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. The organization also accepts commissions from German federal and Länder ministries and government departments to participate in future-oriented research projects with the aim of finding innovative solutions to issues concerning the industrial economy and society in general.

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, accelerating technological progress, improving the acceptance of new technologies, and not least by disseminating their knowledge 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, in other scientific domains, in industry and in society.

Students working 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.

At present, the Fraunhofer-Gesellschaft maintains more than 80 research units, including 56 Fraunhofer Institutes, at 40 different locations in Germany. The majority of the 12,500 staff are qualified scientists and engineers, who work with an annual research budget of 1.2 billion euros. Of this sum, more than 1 billion euros is generated through contract research. Two thirds of the Fraunhofer-Gesellschaft's contract research revenue is derived from contracts with industry and from publicly financed research projects. Only one third is contributed by the German federal and Länder governments in the form of institutional funding, enabling the institutes to work ahead on solutions to problems that will not become acutely relevant to industry and society until five or ten years from now.

Affiliated research centers and representative offices in Europe, the USA and Asia provide contact with the regions of greatest importance to present and future scientific progress and economic development.

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

Fraunhofer Surface Technology and Photonics Alliance

Surface technology and photonics are two of the core competences of the Fraunhofer-Gesellschaft. The former is of essential importance in the manufacture of optical and optoelectronic components and products. The latter, and laser technology in general, is becoming increasingly common in production processes and metrology in connection with surface engineering. They are both key technologies, being employed to a growing extent in a variety of applications, including production systems, optical sensors, information and communication technology, and biomedical engineering.

In order to coordinate the targeted application of their expertise and define joint strategy plans, six Fraunhofer Institutes employing a total of around 1000 staff and working with a budget of 75 million euros have joined forces in the Fraunhofer Surface Technology and Photonics Alliance (VOP). The core competences of the alliance lie in the development of thin-film systems and coating processes for a wide variety of applications, surface functionalization, the development of laser sources and micro-optical and precision-engineered systems, materials processing and optical metrology.

In the immediate future, the alliance intends to focus its research activities on the advanced development of innovative laser sources such as fiber lasers and to nurture the industrial deployment of terahertz technologies.

The alliance comprises the Fraunhofer Institutes for

- Applied Optics and Precision Engineering IOF
- Electron Beam and Plasma Technology FEP
- Laser Technology ILT
- Material and Beam Technology IWS
- Physical Measurement Techniques IPM
- Surface Engineering and Thin Films IST

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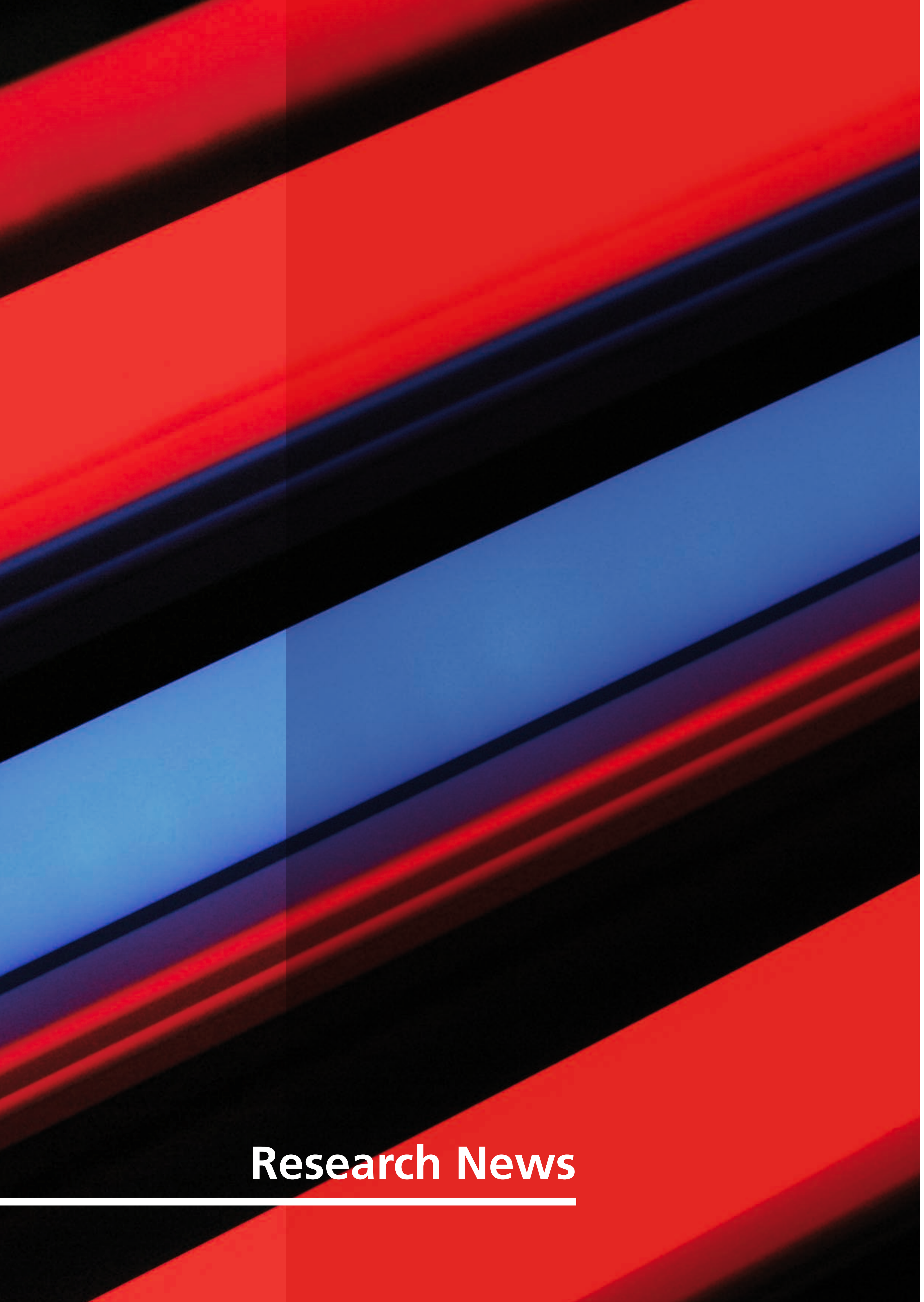

Research News

Research News

ELECTRON BEAM TECHNOLOGY

PULSE MAGNETRON SPUTTERING

PLASMA ACTIVATED HIGH RATE DEPOSITION

Transparent, scratch-resistant layers on large area substrates

Dr. Henry Morgner

Plastics and metals have very varied properties which enable them to be used for a wide range of different applications. These two groups of materials possess completely different surface hardnesses. In order to expand the uses of both plastics and metals it is desirable to increase the surface hardness and abrasion resistance without significantly altering the optical appearance of the surface. Transparent oxide layers can fulfill this task, even on high-area substrates such as plastic films, plastic and metal sheets and strip metal. The deposition of these oxide layers can be carried out very productively using plasma-activated high-rate deposition.

The deposition of SiO_x on plastic substrates using the HAD process (Hollow cathode arc Activated Deposition) has been a main area of work at the FEP since 1995. Work to expand the process technology for coating metal and glass substrates started in 2004 within an internal Fraunhofer commercially-orientated strategic alliance (WISA transparent scratch-protection).

Substrate hardness and the hardness of the abrasion-resistant SiO_x layers

Substrate	Hardness of the substrate [GPa]	Hardness of the SiO_x layers [GPa]
Polycarbonate	0.11*	2 … 3
PET	0.15*	2 … 3
PMMA	0.18*	2 … 3
Ferritic steel (St 14)	ca. 1	8 … 15
High-alloy steel (X5 CrNi 18.10)	3 … 4	8 … 15
Float glass	ca. 6	8 … 10

Table 1: Hardness measurement by nano-indentation;
*Ball indentation

Requirements on scratch-resistance

Scratch-resistance is strictly-speaking the resistance to the effects of pointed or sharp objects. The abrasion resistance is used to evaluate the quality of scratch-resistant layers. High abrasion resistance means there is high resistance to abrasive wear, namely to removal of material via scratching, micro-cutting or micro-fracturing which occur when there is interaction of the surface with hard particles. Damage to the surface alters the optical properties and can be measured by the increased scattering of reflected light – loss of gloss – or for transparent systems as scattered light or haze in transmission. Adequate surface hardness is a key prerequisite for high abrasion resistance. Other key factors are as high as possible elasticity and good adhesion of the hard layers to the substrate.

The hardness of transparent abrasion-resistant SiO_x layers can be adapted to a very broad range of substrate material hardness. Table 1 compares the surface hardness of different materials and the hardness of the SiO_x layers that can be achieved on these materials. The requirements on abrasion-resistant layers can be summarized as follows:

- Mechanical properties:
  - Excellent adhesion, even in the presence of moisture (plastic substrates)
  - Low internal stress (plastic)
  - Elastic and plastic deformability
  - Resistance to temperature changes
  - High hardness
- Optical properties
  - High transparency
  - (k: 0.001… 0.01 @ 550 nm)
  - Low refractive index
  - UV protection (plastic)
  - Highly uniform layer thickness
- Requirements on the coating technology
  - Ability to deposit layers having the above-mentioned properties
  - High productivity – high coating rates on large areas
  - Low thermal loads (plastic, e.g. PC, max. temperature < 130°C)

The aforementioned requirements on the layer quality and productivity necessitate activation of the vapor and have promoted the development of plasma-activated high-rate deposition.
Plasma-activated high-rate deposition using the HAD process (Hollow cathode arc Activated Deposition) is suitable for depositing thick, transparent, abrasion-resistant layers having a typical thickness between 2 and 6 µm. For economic reasons coating rates of the order of 100 nm/s are required. Layer thickness uniformity in the range between ±5% and ±10% is acceptable for most applications.

The HAD process uses the dense plasma of hollow cathode arc discharge sources to activate the vapor. The charge carrier density of the plasma is typically in the order of 10^{12} cm^{-3} and is therefore well matched to the high particle density of the vapor.
This process can be used to deposit colorless, transparent oxide layers of high packing density and high hardness on plastic substrates, without exceeding the maximum permissible thermal load of the plastic substrates.

HAD coating technology

The HAD process combines the reactive evaporation of oxides or reactive evaporation of metals at high rates with activation via the hollow cathode arc discharge plasma. Processes involving the deposition of SiO_x and Al_2O_3 are at the most advanced stage of development. TiO_2, a material with a high refractive index, can also be deposited. Al_2O_3 can be deposited at a coating rate of 50 ... 150 nm/s via the reactive evaporation of aluminum. SiO_x layers are preferably deposited at typical coating rates of 50 ... 600 nm/s by electron beam evaporation of SiO_2. This surpasses the coating rates of magnetron sputtering technology by two orders of magnitude. The remainder of this article will now focus on SiO_x based layers.

The dense plasma produced by hollow cathode arc discharge can be described by the electron energy distribution function (EEDF) in the plasma.
Fig. 1 shows a typical EEDF consisting of a Maxwell distribution of the isotropic electrons superimposed by a group of directed electrons, the beam electrons

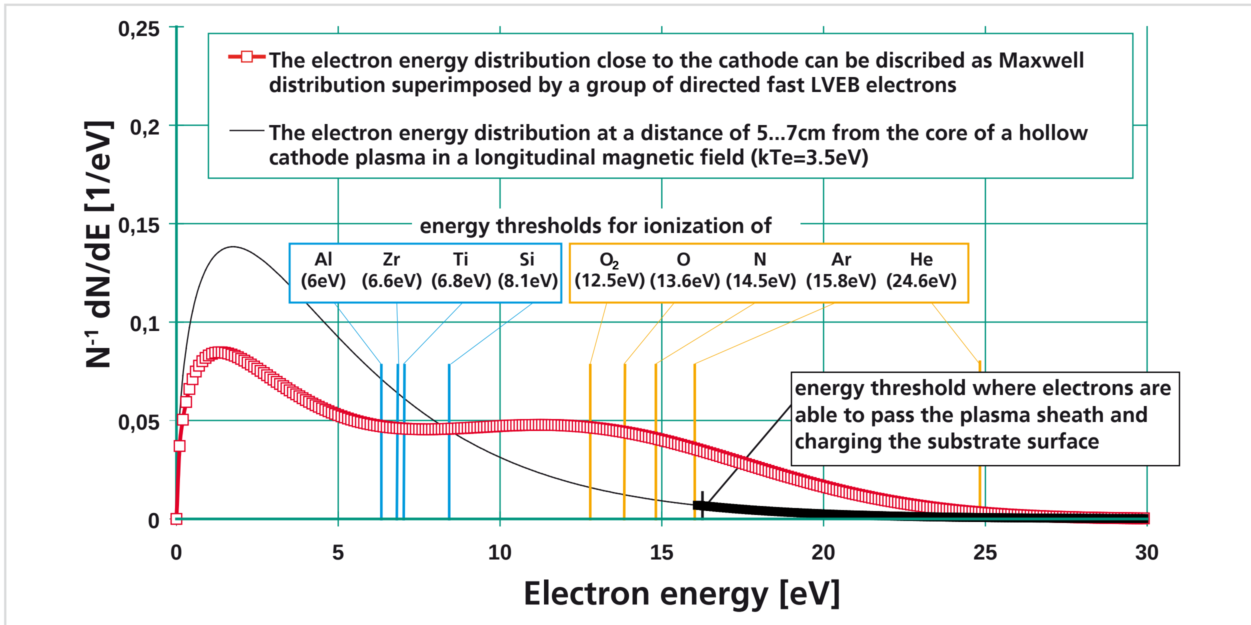

Fig. 1: Electron energy distribution function in the hollow cathode plasma
▸ in the core of the discharge (line with small squares)
▸ at a distance from the core of the discharge which corresponds to the distance of the substrate (solid line).

or LVEB (Low Voltage Electron Beam). The EEDF of the electrons in the plasma contains a high fraction of electrons which exceed the ionization threshold of the particles in the vapor (6 ... 16 eV). For this reason, charge carrier densities over 10^{12} cm^{-3} can be attained. This results in ion flux densities on the substrate of 30 ... 80 mA/cm². The energy of the "electron tail" of the EEDF, which is responsible for charging the insulating substrate surfaces, determines the self-bias potential on the substrate surface. The self-bias potential is estimated to be 20 … 30 V, whereby it is assumed there is transfer of the EEDF into a Maxwell distribution in the vicinity of the substrate (see Fig. 1, solid line).
The HAD process is used for coating plastic films, plastic sheets, metal substrates and glass substrates. The plasma-activated electron beam evaporation of SiO_2 from a rotating quartz tube is shown in Fig. 2. In this case there is close contact between the dense plasma and the substrate.

Deposition of SiO_x and layer properties on plastic substrates

The deposited SiO_x layers are glass-like, dense and amorphous. The hardness of the SiO_x layers deposited onto plastic is 2 to 3 GPa. The limits for this are set by the limiting thermal load on the substrate. The abrasion resistance of these layers, having a minimum thickness of 5 ... 6 µm, is however excellent (Fig. 3). These thick SiO_x layers on polycarbonate have similar abrasion resistance to float glass (2% haze according to the Taber Test). The abrasion resistance is very dependent on the layer thickness. A layer thickness of at least 5 µm is required to give excellent abrasion resistance.
Table 2 summarizes the characteristic properties of the layers. The layer properties can be considerably improved by organic modification of the SiO_x layers. This increases the elasticity of the layers (Fig. 4). The strain-to-microcracking is about 0.6 ... 0.8% for pure oxide layers and can be increased to almost 2% by the organic modification, although this is accompanied by a decrease in hardness (Fig. 4). There is however a technological process window where there is increased elasticity without detriment to the abrasion properties of the layers. The increased elasticity is a necessary precondition for application of the layers outdoors. This allows the different coefficients of expansion of the substrate and layer to be compensated over a wide temperature range. For outdoor applications a temperature range of 100 °C must be taken into account. The change in length of polycarbonate is 7 mm per meter for a temperature change of 100 K. In contrast, the thermal expansion of silicon dioxide is almost zero.

The coating trials took place in a web coating plant suitable for a web width of 400 mm and equipped with a HAD module. The plant possesses both a web transport system for films and a transport system for sheet substrate materials. Fig. 5 shows a rear triangular window for a car made of polycarbonate and coated on both sides. The following are estimated values for the productivity and costs for a coating width of 1.2 m and a film thickness of 4 µm:

- Productivity: ca. 0.5 million m² per year
- Coating costs: ca. 4 to 5 € /m²
  (4800 h effective annual production time)

Microstructure:	Dense, amorphous
Refractive index:	≈ 1.45
Dynamic hardness:	≈ 3 GPa (nano-indentation) for purely inorganic layers ≈ 2.2 ... 2.7 GPa for organic - modified layers
Elasticity:	1.8% strain-to-microcracking for organic - modified layers
Adhesion:	Peel force ≈ 3 N/cm (on polycarbonate)
Abrasion resistance: (Taber Abrasion Test)	Haze: 2%* after 1000 rev. For organic-modified layers (friction wheel: CS-10F; load: 500 g); layer thickness 6 µm

Table 2: Properties of the SiO_x layers on PC sheet substrates
* (the haze value for float glass is also 2% under the same conditions)

The coating of plastic substrates covers both films and sheet substrates. Prospective applications for coated films include:

- **Heat protection films**
  Heat protection films reduce heat passage through windows by reflecting IR radiation. These films have an optical layer system and are laminated onto the pane of glass. The additional SiO_x layer protects the optical system against scratching and abrasion. For optical reasons the abrasion-resistant layer is applied under the optical layer system.
- **Sun reflectors**
  High-area, highly reflective mirrors for solar power plants utilize a silver coating on a plastic film. Thick, highly transparent oxide layers are required here for abrasion and corrosion protection.
- **Colorless, transparent, protective films on windows made of safety glass, the surfaces of furniture and other surfaces**
  Oxide-coated plastic films can be laminated onto plastic windows or decorative surfaces without adversely affecting the transparency and shade of color.

Due to the relatively low thermal exposure in the coating process, SiO_x layers can also be deposited directly onto plastic sheets or components. Potential applications for SiO_x layers on plastic sheets:

- **Car windows**
  The main advantages of using polycarbonate for car windows are its lack of brittleness, toughness, weight reduction and the increased

Fig. 2: Electron beam evaporation from a rotating quartz tube with plasma-activation by two hollow cathode arc discharge sources.

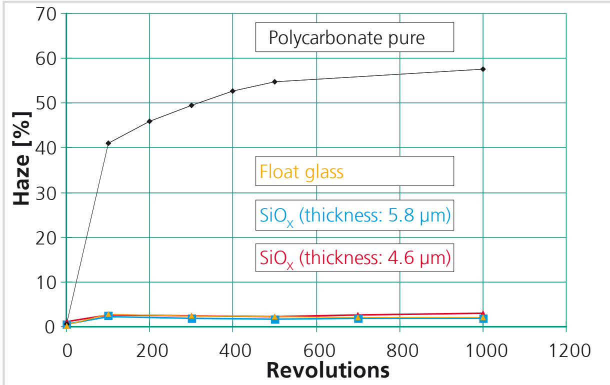

Fig. 3: Abrasion resistance of an SiO_x layer on PC sheets with an organic hard-coat as sub-layer. Coating rate: ≈ 300 nm/s. (CS-10F friction wheels, 500g load, 1000 rev.).

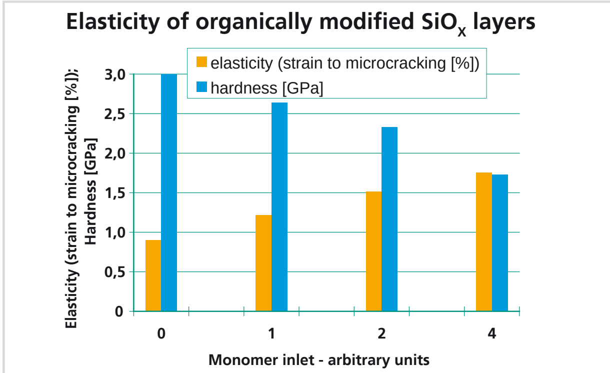

Fig. 4: Increased elasticity of the organic - modified SiO_x layers.

design freedom. In practice a scratch-resistant surface is required. Due to the bending of the polycarbonate surface, lamination with a coated film is preferred to direct coating.

- **Display windows and safety glass**
  For these applications the direct coating of plastic sheets is an alternative to laminating with a coated film.
- **Displays for mobile telephones**

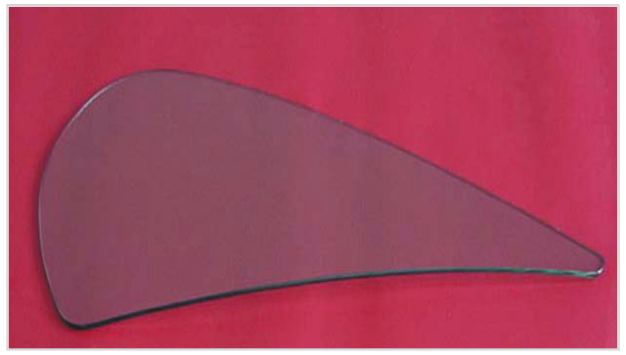

Fig. 5: SiO_x coated rear triangular car window.

Deposition of SiO_x layers on metal and glass substrates

Metal substrates are considerably harder than plastic substrates, but less hard than oxides. Metallic surfaces can also be scratched or damaged by abrasion. The abrasion resistance of these substrates can be increased by the presence of a hard surface layer. The higher thermal load limit of metal substrates compared to plastic substrates (see Table 1) meant that SiO_x layers of considerably higher hardness could be developed. This higher hardness is due to the following facts:

- A higher ion flux density can be used during the coating because the heat input per applied quantity of layer can be increased.
- Metal substrates can be coated at temperatures of several hundred degrees Celsius.

The necessary increase in the degree of plasma-activation and ion flux density at the substrate was achieved using booster anodes.

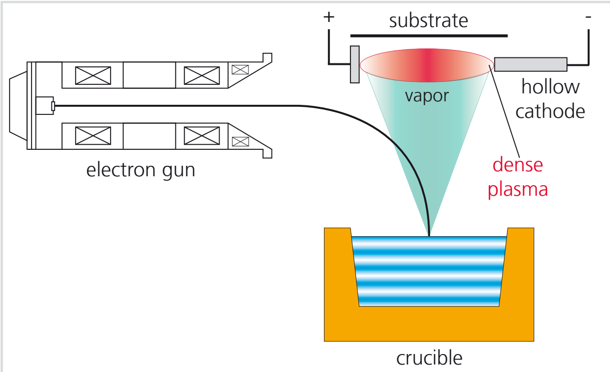

Fig. 6: HAD technology in the "MAXI"

Hardness	8 ... 10 GPa	15 GPa
Refractive index	1.45 … 1.60	1.58 … 1.68
Extinction coefficient	3×10^{-4} ... 3×10^{-3}	7×10^{-3} ... 1×10^{-2}
Elasticity	1.0 … 1.4%	

Table 3: Properties of the SiO_x layers on metal substrates

Fig. 7: Coating chamber.

The process technology (Fig. 6) was transferred to the "MAXI" in-line coating plant. Fig. 7 shows the coating chamber and Fig. 8 the electron beam evaporation in conjunction with the HAD plasma-activation with booster anodes. The thermal load acting on the substrate is in the range between 20 and 50 Ws / µm cm^2. The typical comparable value for the coating of polycarbonate sheets is 5 Ws / µm cm^2. The specific heat input is therefore 4 to 10 fold higher than the typical value for coating plastic.

The layer properties summarized in Table 3 were achieved due to the higher degree of plasma-activation coupled with the higher substrate temperature in the region of 100 ... 500°C. Surprisingly, the transparency of the organic-modified SiO_x layers was also maintained for hard, sub-stoichiometric SiO_x layers. The transparency is virtually unimpaired up to a layer hardness of 10 GPa. There is slight absorption for very hard layers (15 GPa). The extinction coefficient of 1 x 10^{-2} is however acceptable in most cases for top layers on metal substrates. The graph in Fig. 9 shows the layer hardness as a function of the stoichiometry of the layer (O/Si ratio). The lower values for the O/Si ratio occur with more intense plasma-activation. The SEM micrograph in Fig. 10 shows the dense microstructure of the layer. The hardness values cannot be explained solely by the dense microstructure. In particular, hardnesses greater than the hardness of the amorphous SiO_2 bulk material (9.3 GPa) cannot be explained. X-ray diffraction at grazing incidence was able to detect nano-crystalline silicon in the very hard SiO_x layers (Fig. 11).
These layers can be designated as "silicon-rich SiO_2 layers (SRSO)", namely layers which are known to deposit at lower rate at high substrate temperature and possess photoluminescence properties.

The extremely high hardness of the SiO_x layers can therefore be explained by this nano-functionalization. Fig. 12 gives an impression of the high-alloy steel strips coated in the "MAXI" pilot plant.
The HAD technology allows the coating of strips and sheet materials with extremely high productivity.
The productivity of an industrial in-line web coating

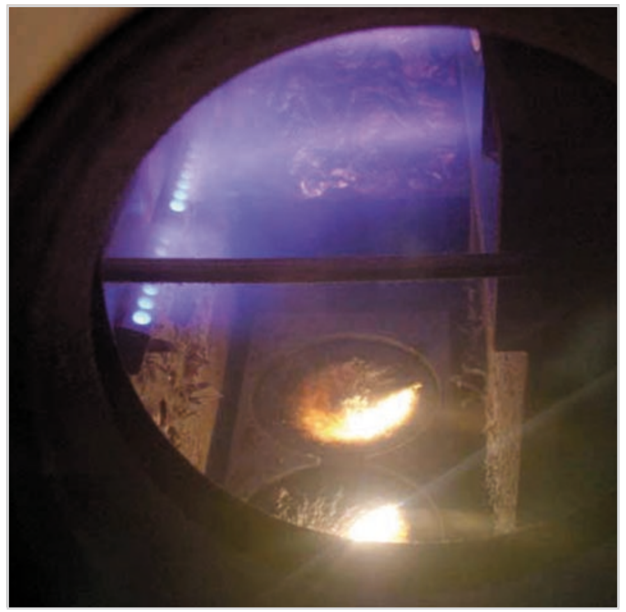

Fig. 8: EB evaporation of SiO_2 granulate in combination with the booster anode plasma.

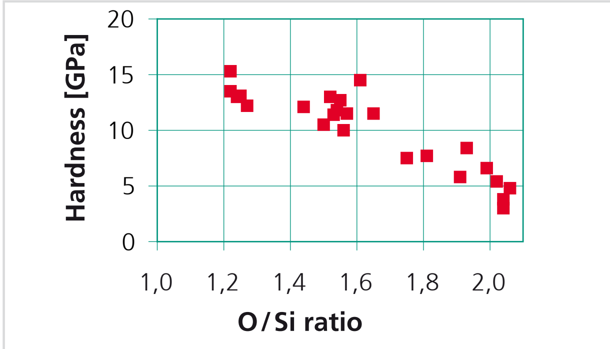

Fig. 9: Effect of the stoichiometry (O/Si ratio) on the layer hardness.

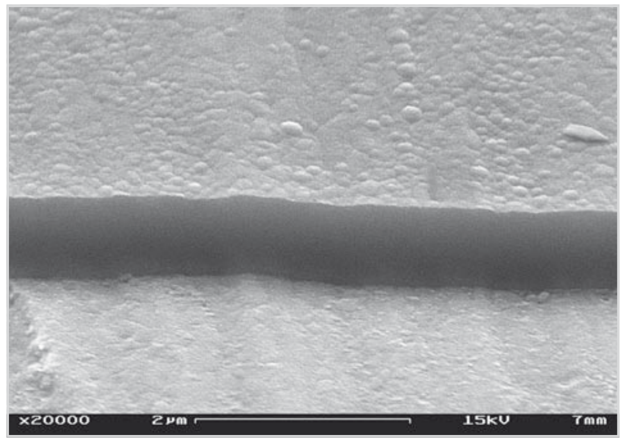

Fig. 10: SEM micrograph of a fracture in a hard, 1 µm thick SiO_x layer. Hardness: 15.3 GPa.

plant of 1 m web width producing a 2 µm thick transparent, abrasion-resistant SiO_x layer is estimated to be 0.3 million m² per year. The relevant coating costs are ca. 5 €/m². Potential applications for coated metal substrates are as follows:

- Fronts for kitchens and kitchen appliances – anti-fingerprint properties and scratch-resistance
- Surfaces of architectural paneling

A layer hardness of 8 to 10 GPa was achieved on glass substrates. In all cases the extinction coefficient was the order of 10^{-4} and is hence extremely low. Increasing the surface hardness of glass from 6 GPa to 8 ... 10 GPa results in very high abrasion resistance. In the Taber Abraser test under standard conditions used in the car manufacturing industry, virtually no worsening of the haze value due to the abrasion test could be detected (Fig. 13).
The following application is conceivable for glass substrates:

- Coating of car windows in regions where there are sand storms

Further potential applications will be proposed in a subsequent publication of the project findings.

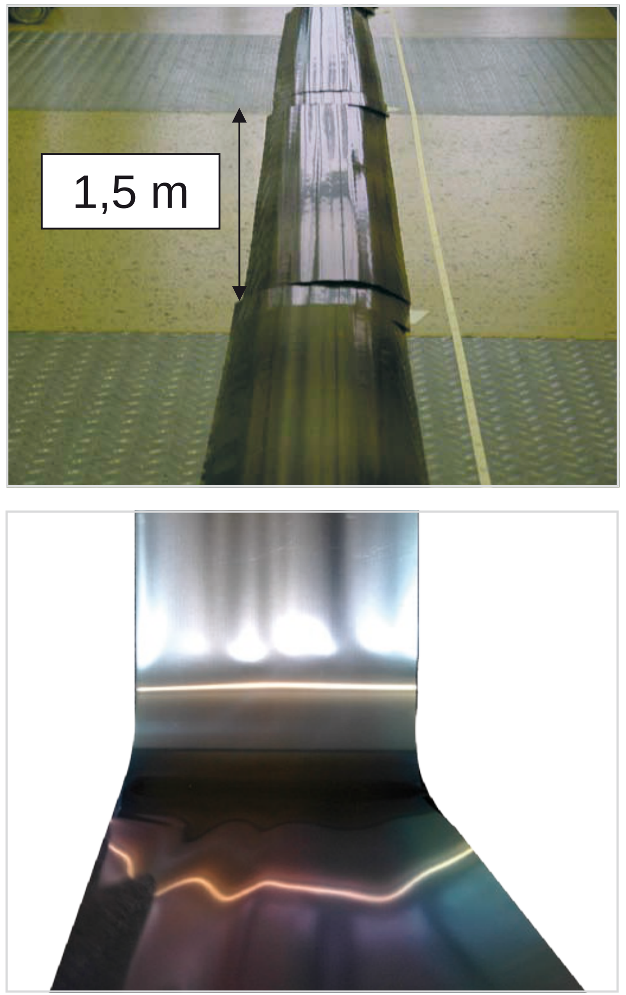

Fig. 12: Strip steel (high-alloy steel) coated with a 2 µm SiO_x layer (substrate thickness: 100 µm).

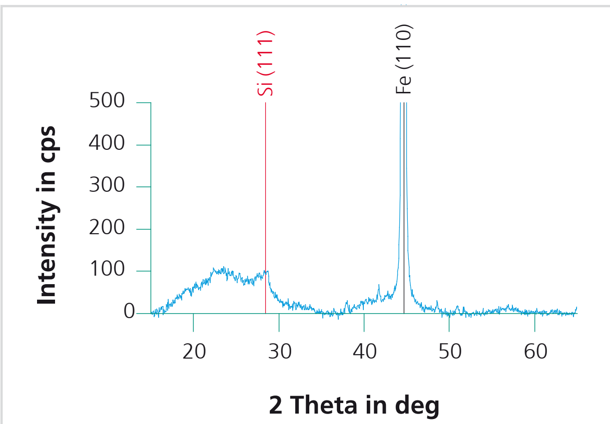

Fig. 11: X-ray diffraction at grazing incidence: Evidence of nano-crystalline Si.

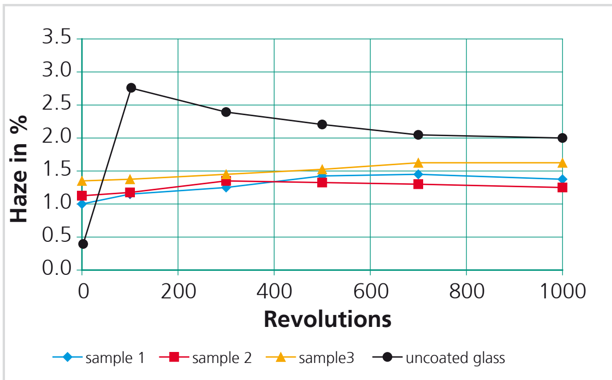

Fig. 13: Transparent, hard (ca. 9 GPa) SiO_x layers on glass substrates subjected to the Taber Abraser test. Parameters: Friction wheels CS-10F, 500 g load.

novoFlex® – New applications in the surface modification of flexible products

Dr. Nicolas Schiller

In 2006 the "Coating of plastic films" business field was renamed "Coating of flexible products". This step completed something that had long been reality, namely that in addition to plastic films the surfaces of flexible membranes, very thin metal films, paper and textile materials are being modified by vacuum coating for a variety of flexible products. The aforementioned flexible substrates possess a number of features which make them of interest for a variety of products. For example, due to their flexibility they can be used on curved surfaces. Another feature is their low material usage per unit area.
A key criterion is also that the flexible substrates are able to be coated very efficiently and with high area throughput by vacuum methods in web coating plants (roll-to-roll). This roll-to-roll processing has considerable potential for reducing costs.

The modification of surfaces by applying thin layers using vacuum methods has the advantage that it allows the attractive properties of a substrate to be combined with those of the layer-forming material. This allows a variety of features to be introduced, for example:

- Permeation barriers to oxygen and water vapor
- Metallic sheen
- Scratch-protection, abrasion resistance
- Conductivity
- Color effects
- Optical filter effects

Ever since being founded the FEP has constantly expanded its activities on the coating of plastic films and flexible products. The FEP is today an important provider of R&D services in this area. A particular strength of the FEP is the scaling up of coating technologies for production processes (see Figure 1). Within the Fraunhofer-Gesellschaft the FEP occupies a unique position regarding the coating of high-area flexible materials using vacuum methods.

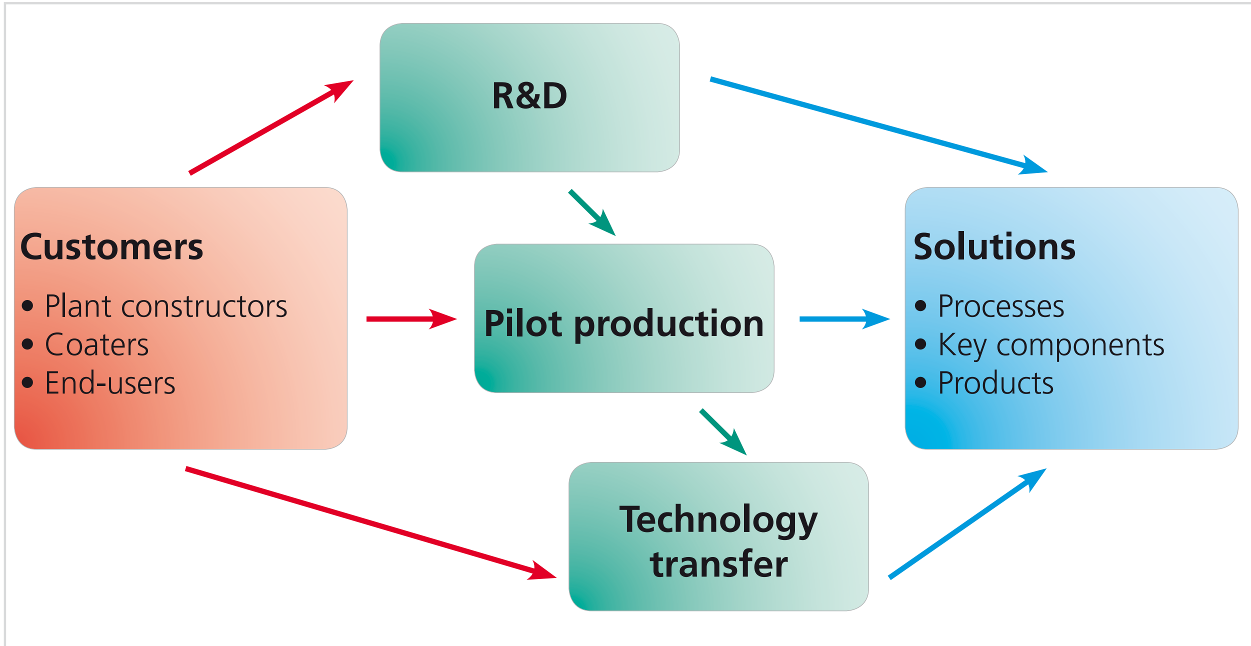

Fig. 1: The range of services provided by the "Coating of flexible products" business field covers R&D, pilot production and technology transfer. Our customers are constructors of vacuum coating plants, operators of such plants and end-users who integrate the coated materials into other products.

novoFlex® – New applications in the surface modification of flexible products

Vision of the future

Mark Twain is thought to have quipped: “Making a prognosis is difficult, especially when it concerns the future”. In our case, there is indeed some uncertainty attached to predicting the future direction of development of a business field. From our many contacts with industry we have however been able to identify new product areas which will become of increasing importance for our business field:

- Photovoltaic technology (on plastic films and metal films)
- Flexible displays
- Fluorescent films
- High-performance batteries
- Forgery protection
- Polytronics
- Sensor technology
- Antibacterial medical products
- RF-IDs

There are also a variety of potential niche applications including barrier films for different technical applications, membranes, laser projection walls and decorative applications.

From a technological point of view there is a demand for:

- the combining of different coating technologies
- multiple layer systems
- in-line systems
- customer-specific coating (specialty roll-coating)

The new novoFlex® 600 test plant was designed with these technological requirements in mind.

novoFlex® 600: “If you want to build a ship...”

Antoine de Saint-Exupéry said “If you want a ship don’t herd people together to collect wood and don’t assign them tasks and work, but rather teach them to long for the endless immensity of the sea.”
The construction of a new test plant is not dissimilar to building a ship. The new test plant should enable the team to undertake many projects and take them to new “shores”. A great deal of thought and consideration went into the design phase. Current and future demands of the market were conscientiously and enthusiastically researched by the team. In close collaboration with VON ARDENNE Anlagentechnik GmbH the result was finally a concept for a plant which would meet the long-term market requirements. The name novoFlex® 600 was coined for the innovative plant. The plant is currently being built by VON ARDENNE Anlagentechnik GmbH. Operational start-up is planned for the first half of 2007.

Table 1 summarizes the technical specifications of the plant and Figure 3 schematically shows the plant. The novoFlex® 600 has two process rolls with a total of 5 coating stations. The plant has the facility to combine different coating technologies: evaporation, magnetron sputtering and PECVD. This facility to combine several coating technologies will allow new avenues to be opened for the vacuum coating of flexible substrates. The width of the substrates and the web speed are close to those of an industrial pilot plant, so this will also allow scale-up to pilot production. The web winding system of the novoFlex® 600 allows the coating of both sides of the substrate in one pass.

Flexible circuit supports

The semiconductor industry is under constant pressure to produce ever thinner and hence lighter, more flexible and cheaper circuit boards. In particular, demands for further volume and weight reductions and improved high-frequency properties are being requested by the car manufacturing industry, the consumer electronics industry (e.g. miniature MP3 players) and mobile radio technology sector (mobile phones). Over the coming years strong growth is expected in the demand for flexible circuit boards. Polyethylene terephthalate (PET) and polyimide films are currently used as materials for flexible circuit supports. Compared to PET, polyimide can be used at higher temperatures and undergoes less shrinkage after exposure to heat. Consequently, polyimide is used for many applications where high thermal stability is important, for example where soldering is carried out.

Layer properties	Product applications
Permeation barriers to water vapor and oxygen	▸ Transparent packaging films for foods ▸ High barrier films for vacuum insulation panels ▸ High barrier layers for displays
Conductivity	▸ Transparent electrodes for display applications ▸ High-performance capacitors
Corrosion protection	▸ Electrodes for high-performance batteries
Color effects	▸ Laser-writable labels
Optical filter effects	▸ Solar protection layers ▸ Antireflection layers ▸ Forgery protection

Table 1: Layer properties and product applications relevant to ongoing development projects.

Web width (maximum)	650 mm
Coating width (maximum)	620 mm
Substrate thickness	3 ... 250 µm
Web winding	▸ Winding direction fully reversible ▸ Coating of both sides in one pass
Web speed	0.1 ... 600 m/min
Coating stations	5
Substrate pretreatment	In-line substrate pretreatment with a linear ion source
Coating technologies	▸ Thermal evaporation ▪ plasma-activated evaporation ▪ reactive process management ▸ Magnetron sputtering ▸ PECVD
Other technologies which are possible via expansion	▸ Electron beam evaporation ▸ Thermal evaporation (2nd station) ▸ Structuring

Table 2: Technical specifications of the novoFlex® 600.

Flexible circuit supports made of polyimide are nowadays metallized using a variety of techniques. One problem with direct metallization in a vacuum is that it is difficult to get an adherent copper layer. Here, the adhesion strength of the layer must also be guaranteed during the subsequent structuring processes at elevated temperatures. For this reason a project is being undertaken, funded by the Saxon Ministry for Trade, Industry and Employment, to improve the adhesion strength of copper on heat-resistant plastic films such as polyimide and PEEK by applying adhesion-promoting layers.

Permeation barriers for technical applications

Permeation barrier layers (also simply called barrier layers) are vital for ensuring the functionality of a range of products. For example, since the early 1960s plastic films modified with an aluminum barrier layer have revolutionized the whole area of food packaging. Such barrier films are manufactured in vacuum plants using so-called roll-to-roll processes.
There is however a growing demand for barrier layers for other applications. There is also a demand for barrier layers with customized properties and with additional functions such as conductivity.

A project, funded by the Federal Ministry for Education, Science, Research and Technology (BMBF), is being undertaken to achieve the following objectives:

- To develop multifunctional barrier layers on flexible materials;
- To develop an innovative, high-productivity process for manufacturing multifunctional permeation barrier layers on flexible substrates;
- To integrate the coated flexible materials into a variety of innovative products, for example flexible solar cells.

Federal Ministry of Education and Research

SÄCHSISCHES STAATSMINISTERIUM FÜR WIRTSCHAFT UND ARBEIT

Fig. 2: Future applications.

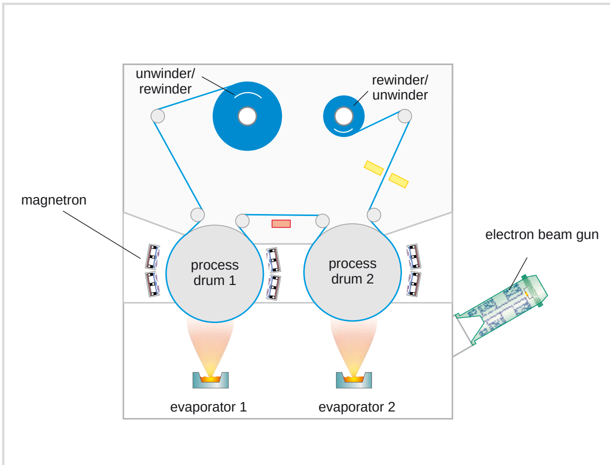

Fig. 3: Schematic representation of the novoFlex® 600.

Building bridges: Pilot production for promoting rapid market introduction of new products

Dr. Nicolas Schiller

The objective of research and development is to develop new products and technologies up to the point of market introduction. This work is carried out in close collaboration with partners from industry who take over the commercialization of the products and technologies at the end of the development phase.

A critical point is often reached at the end of the development phase. Due to long delivery times customers often do not yet have their own production plants and in other cases the market does not yet justify companies investing in their own production plants. The FEP makes its pilot plant facilities available in order to fill this gap between the development work and industrial production. On the basis of pilot plant production the market can be developed by the industrial partner. The pilot production phase also offers the opportunity to identify and rectify problems associated with technology scale-up and industrial production.

Pilot production can therefore be seen as a continuation of the development work, using other equipment. In this phase we view ourselves as being the builder of a bridge between the development work and the industrial production.
The FEP has already developed several technologies up to the pilot production phase and this is illustrated by the following two examples.

Laser-writable labels

Laser-writable labels allow rapid and easy labeling, for example with serial numbers, by an inline laser in a production process. Conventional labels based on coatings have a number of disadvantages, for example the release of emissions during the labeling. An industrial manufacturer of laser-writable labels therefore developed a label which allows rapid and emission-free labeling. A key component of the product is a black, ultra-thin layer (on a plastic film) that can be removed by a laser. The FEP was

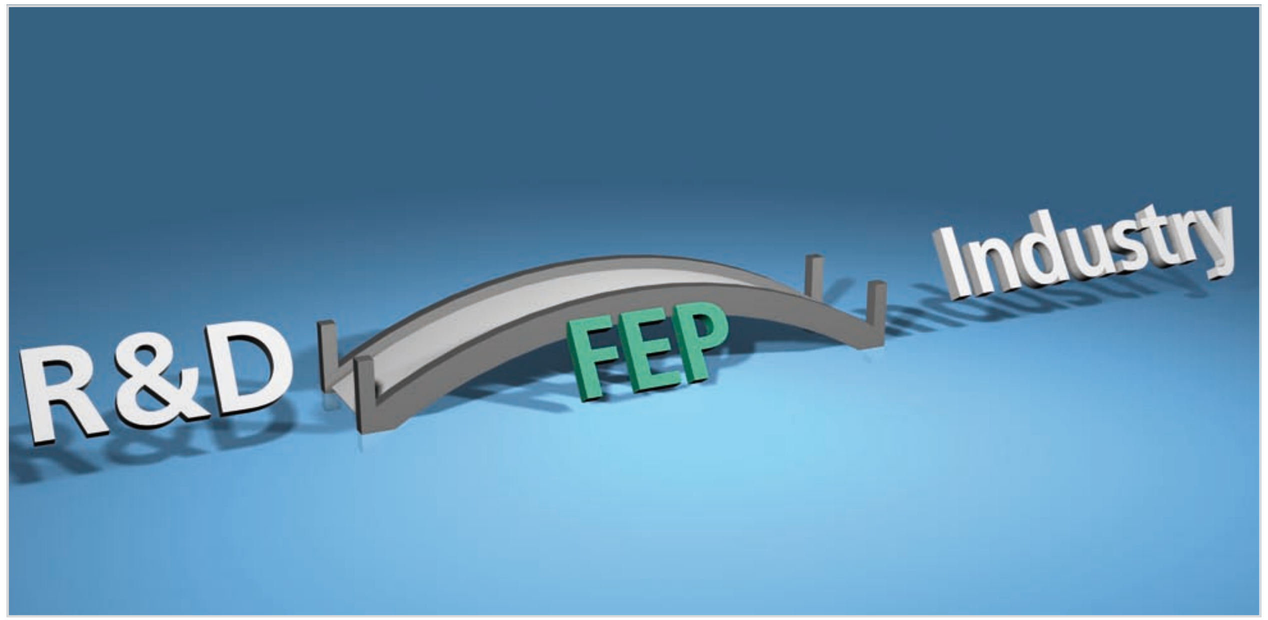

Fig. 1: The FEP is building the bridge between R&D and the industry.

commissioned to develop a process for the efficient coating of the plastic film.

Based on the list of requirements of the industrial partner the FEP developed a coating process based on high-rate evaporation of aluminum under addition of oxygen. In order to guarantee the quality of the product a process control system was developed. This control system was patented.

The process was successfully installed in a pilot plant at the FEP. Over the last two years several tens of thousands of square meters of plastic film have been coated as part of the pilot production. In order to meet the growing demands for production capacity, the process and a system for in-situ monitoring of the product quality were successfully transferred to an industrial coater.

Commutators for heavy-duty batteries

Hybrid vehicles and electric vehicles are currently being given increased attention. Rechargeable heavy-duty batteries are vital for these vehicles. Progress in battery technology will be decisive in determining whether electrical vehicles become a reality of everyday life in the future. Batteries based on lithium ion technology offer high energy density, high cycle-stability, low self-discharge and favorable operating temperature.

Commissioned by a leading manufacturer of high-performance Li batteries, the FEP is developing a process for manufacturing commutators for these batteries. Using plasma-aided evaporation, a protective layer is being deposited on a thin aluminum film. Following initial experiments to demonstrate the feasibility of the process, pilot plant testing is underway. The pilot production phase is currently being carried out in parallel with further development of the coating technology. By 2008 it is expected that demand will have increased several-fold. In collaboration with Unitec Helmsdorf GmbH preparations are already underway to transfer the process from pilot production to industrial production. ■

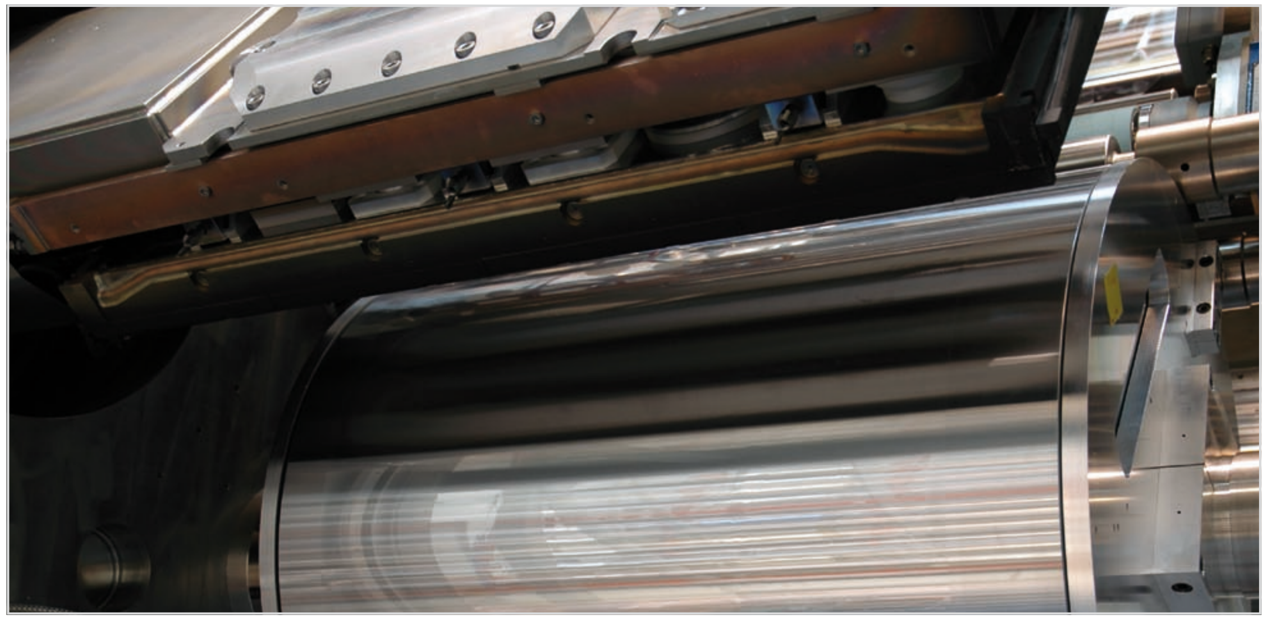

Fig.2: The equipment technology of the FEP allows a development under industrial-relevant conditions as well as pilot production. (Detail of the coating equipment novoFlex® 600)

FLEXCELLENCE- a collaborative European project to develop silicon-based thin film solar cells on flexible substrates

Dr. Matthias Fahland

The key challenges of global R&D today are securing energy supplies for the coming decades and retarding climate change caused by anthropogenic CO_2 emissions. Undisputed here is the fact that technologies for utilizing renewable energy resources will be vital for resolving these challenges. The demands on the various funding organizations and expectations of the research institutions are high. In 2005 Germany spent a total of about 100 million euros funding research projects in this area [1].

This level of funding is necessary because the goals are very ambitious. By 2010 the target for the fraction of energy being generated from renewable resources is to be 10% of the total energy generation. This represents an enormous increase, given that this fraction is presently only 4.6% [2].

Without doubt the most elegant way of recovering energy is direct conversion of sunlight into electrical energy, namely photovoltaic technology. The level of funding in this area is accordingly high, with 46% of all funding in Germany last year being directed at photovoltaic projects.

The actual amount of solar energy being utilized is relatively low, with the solar fraction of the total electric power generation in 2005 being just 0.16% [3]. Even when one just considers energy generation from renewable resources, photovoltaic technology occupies the last place. The principle disadvantage of this technology compared to other methods of energy generation such as wind power and solar-thermal power stations is the high cost of manufacturing the solar modules, which naturally results in a correspondingly high energy price. Cost reduction is essential if this technology is going to be successful in the long-term. Possible ways of achieving this are as follows:

- Increasing the efficiency of the cells
- Reducing the manufacturing costs
- Reducing the costs for the infrastructure (for example installation costs)

Since the end of 2005 the Fraunhofer FEP has been a member of the consortium involved in the FLEXCELLENCE project. This is a collaborative European project concerned with all three of the above-mentioned strategies for silicon-based thin film solar cells. VHF Technologies, a Swiss company, is a key project partner. This company already markets flexible solar cells based on thin films of amorphous silicon.

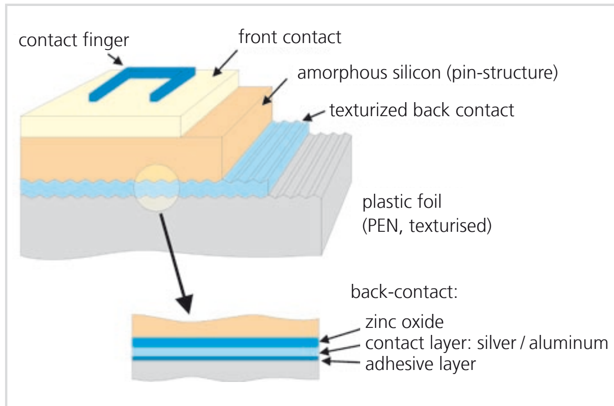

Fig. 1: Structure of a thin film solar cell based on amorphous silicon.

FLEXCELLENCE- a collaborative European project to develop silicon-based thin film solar cells on flexible substrates

Like other thin film solar cells these are manufactured using very small quantities of material, and this means there is considerable opportunity for cost reduction. However, the solar cells currently manufactured by VHF have inferior efficiency compared to established technologies. For this reason, one of the project partners, the University of Neuchâtel, will lead development work on the base concept of a tandem cell. By using a combination of amorphous and microcrystalline silicon the useable spectral region will be expanded considerably. The aim of the FLEXCELLENCE project is to achieve an efficiency of 11%.

The FEP is highly involved in the complex issues that must be tackled to reach this goal. The main task, which is being undertaken within the Coating of Flexible Products Department business field, is the development of the back-contact and its deposition in a favorable-cost roll-to-roll process.
The incorporation of the back-contact into the total layer system is shown in Figure 1 for the example of a thin film solar cell made of amorphous silicon.

The back-contact consists of three layers: a thin metal layer for adhesion promotion, a contact layer made of a good conducting, highly reflective metal and a layer of zinc oxide. The silicon is deposited on this, although this aspect is not the responsibility of the FEP.

The three layer system depicted in Figure 1 must fulfill several functions. Firstly, it is one of the electrodes of the solar cell and must take up the charge carriers generated in the silicon. The contact layer must possess a resistance less than 1 Ω_{sq} in order to fulfill this electrical function as loss-free as possible. In the first year of the project both aluminum and also silver have been tested as materials for the contact layer.

Furthermore, the zinc oxide acts as a barrier against permeation and must prevent the diffusion of metal atoms from the contact layer into the silicon layer which is on top of this.
The three layer system also has an optical function which is extremely important for the efficiency of the cell. It is important to realize that silicon, being a semiconductor with an indirect band gap, has a considerably lower absorption coefficient than other typical solar absorbers with direct band gaps (such as gallium arsenide or cadmium telluride).
The consequence of this is that the silicon absorber has a finite transparency at the layer thicknesses typical of solar cells. The simulation shown in Figure 2 makes this clear. The figure shows the spectrally resolved reflection of a typical back-contact for the system: substrate - chromium (5 nm) - silver (80 nm) - zinc oxide (70 nm), covered with 300 nm of amorphous silicon.

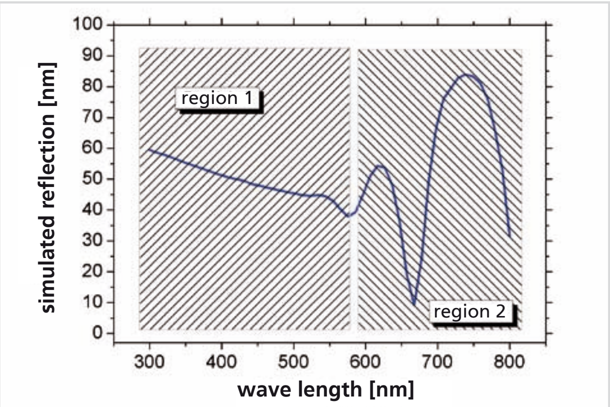

Fig. 2: Simulated reflection of the layer system:
substrate - Cr (5 nm) - Ag (80 nm) - ZnO (70 nm) - a-Si (300 nm).

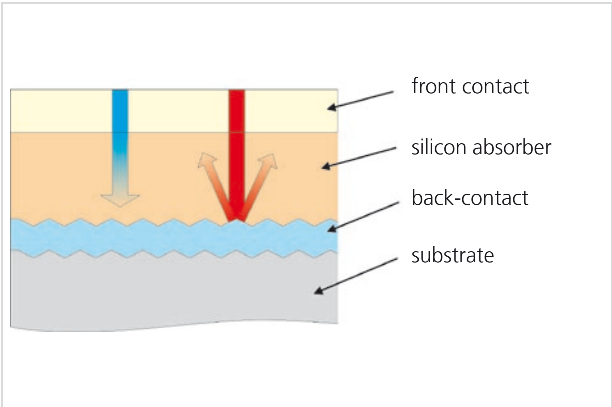

Fig. 3: Schematic representation of the effect of the texture of the back-contact.

In region 1, all light is absorbed by the silicon layer in the first pass. The absorber can thus be deemed to be opaque. This is no longer the case in region 2. This can be seen by the interference pattern resulting from superimposition of the light reflected on the upper side of the silicon layer and the light reflected on the back-contact.

As the silicon layer is no longer opaque in the wavelength region above 600 nm, the high reflection properties of the back-contact have a very important function. It reflects the non-absorbed light back into the silicon as loss-free as possible. This is why highly reflective metals such as silver or aluminum are used. In addition, the zinc oxide provides optical matching between the absorber and the contact layer. Figure 1 shows that the back-contact is not at all smooth, but rather possesses a certain texture. This unevenness is deliberate and ensures that light is not reflected at right angles and hence has to travel a longer path through the absorber. The effect is made clear in Figure 3. It is clear that the texture is especially important for the wavelength region designated as region 2 in Figure 2, namely the red and infrared spectral region. This is indicated by the red arrows in Figure 3 whilst region 1 is indicated by the blue arrow.

In the first year of the project FEP successfully deposited an effective, good adhering back-contact onto polyethylene naphthalate (DuPont Tejin Teonex Q83) and provided this to the various project partners. The University of Neuchâtel has evaluated the effect of the texture of the back-contact. Figure 4 shows the quantum efficiency of microcrystalline solar cells, comparing flat and textured substrates. There are clear differences between the curves in the spectral region in which the absorber layers are not opaque. A key task of the FEP during the project will be the further optimization of the back-contact. The goals are environmental stability and improved optical properties. Vital for achieving the latter goal will be optimization of the texture. Collaboration with the University of Barcelona (a project partner) will be important for this. The work group in Barcelona is able to provide polymer materials with structures.

A typical example of a pyramid structure produced in the project is shown in Figure 5.

In the next phase of the FLEXCELLENCE project the process steps that have until now been carried out at individual project partners will be integrated into a single technology.

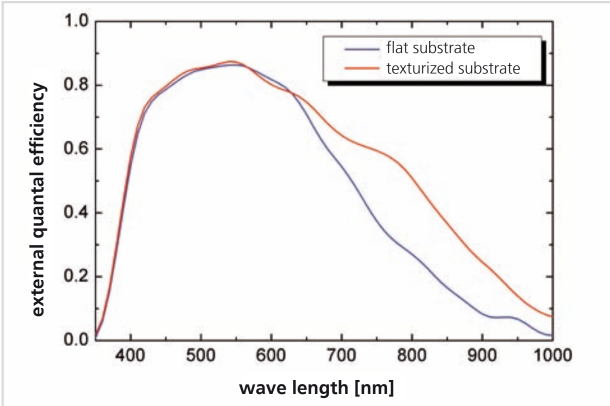

Fig. 4: Comparison of the quantum efficiency of thin film solar cells based on microcrystalline silicon on smooth and textured substrates (with kind permission of the University of Neuchâtel, a partner in the FLEXCELLENCE project).

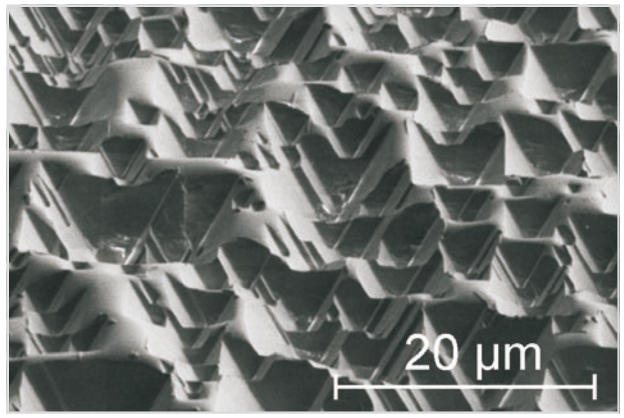

Fig. 5: Surface of a textured PEN substrate (with kind permission of the University of Barcelona, a partner in the FLEXCELLENCE project).

The FEP has an important role to play in this because an effective and reproducible back-contact is indispensable for all further process steps. This will be produced on the coFlex® 600 pilot coating plant in a roll-to-roll process. Figure 6 shows a schematic representation of this plant and the relevant configuration.

Important for the effectiveness of the composite is ion beam pre-treatment with a LIS 65 (Advanced Energy). The two metal layers are then applied, followed by deposition of the zinc oxide layer using a DMS system. An effective base technology has therefore been developed at the FEP and this will be further developed in close collaboration with the partners in the FLEXCELLENCE project. ■

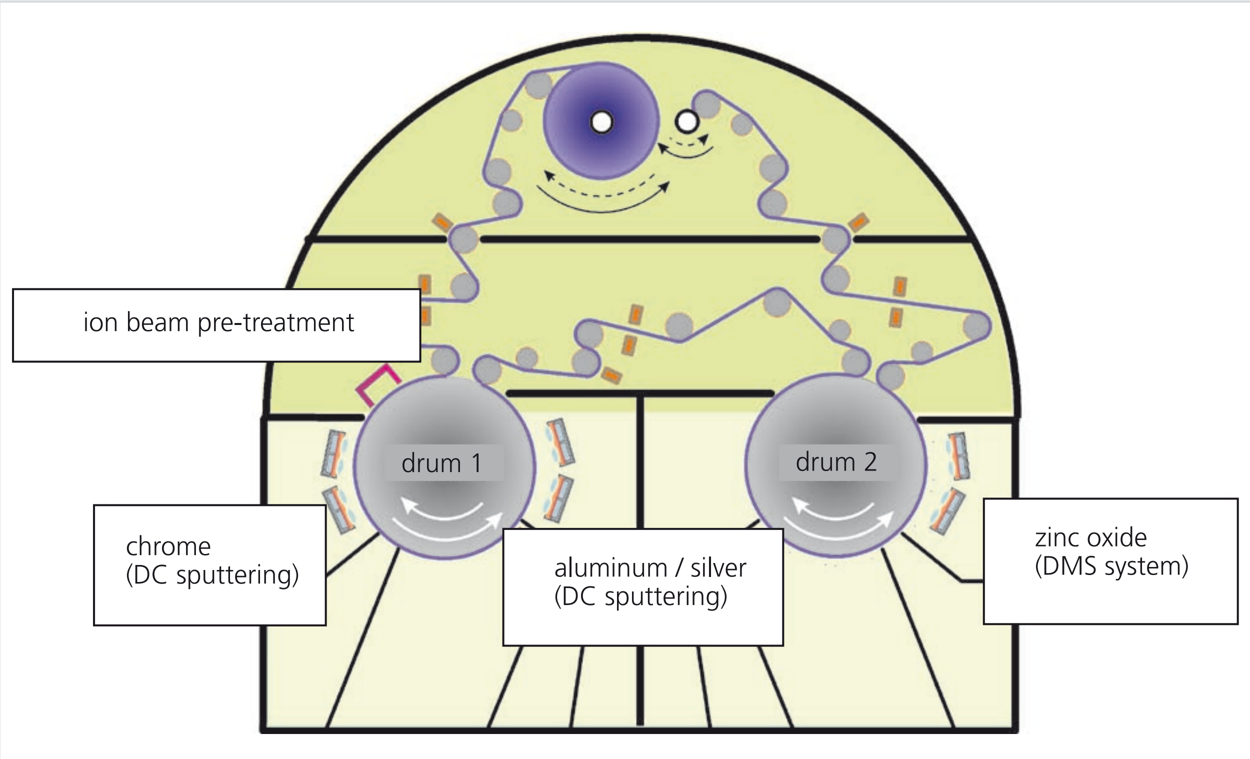

Fig. 6: Configuration of the coFlex® 600 pilot coating plant for deposition of the back-contact of the silicon-based solar cells in the FLEXCELLENCE project.

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[3] Statusbericht zum Energiegipfel, March 2006

Corrosion-resistant coatings for rivets

Dr. Fred Fietzke

Plasma-activated evaporation is being increasingly used in production lines as a high-rate coating technology. For example, plasma-activated electron beam evaporation is used to apply corrosion-resistant layers to sheet steel in continuously working in-line systems. The steel is then further processed in forming and cutting steps. The plasma-activated electron beam evaporation guarantees high coating productivity, low costs per unit area and hence low costs per endproduct. Thin plastic foils are also being coated with layers just a few nanometers thick, to introduce for example barrier functions, in roll-to-roll processes at favorable cost.

This is only possible due to the high deposition rates that can be achieved with boat evaporators, which allow the required layer thickness to be deposited on the films as they travel over cooling rollers at speeds of typically 0.1 m/s to 1 m/s. Compared to sputtering technology, the evaporation technology gives about an order of magnitude higher deposition rate (when one compares layers of the same quality).
For less high quality requirements, the deposition rates can be 100-fold or 1000-fold higher. In order to achieve the best layer properties, evaporation processes are combined with plasma-activation. The most commonly used process for this is hollow cathode activated deposition (HAD) which due to the good control of the plasma parameters and hence control of the coating process is also widely used in industry. The hollow cathode, itself an electron source which can provide electron currents of up to 400 A, is used here as a plasma source. It is either operated in local mode, with a ring anode around the cathode, or it is connected with one or several remotely positioned booster anodes to generate plasma in the space between the vapor sources and the substrate.
The resulting excitation of the vapor and the production of high-energy electrons, ions and neutral particles which participate in the layer formation process means that the layer that is deposited on the substrate has improved properties. In general the objective is to produce a layer having an extremely dense microstructure with as few defects or pores as possible, because the latter have an adverse effect on the desired function of the layer. For example, defects or pores can initiate corrosion.

For some time now the Fraunhofer FEP has been developing a technology aimed at utilizing the benefits of plasma-activated evaporation as a high-rate coating process for applying corrosion-resistant coatings to small mass-produced components. Examples of small mass-produced components are fasteners: bolts, nuts, pins and rivets. Rivets were selected here for our example coating application.

Previously, within a collaborative project funded by the Federal Ministry for Education, Science, Research and Technology (BMBF), the experimental ALMA 1000 plant was constructed for coating bulk products using HAD. This work was undertaken as part of the subproject "Basics for using plasma-activated vacuum evaporation to treat mass produced goods" (PLAVAMAS).

This plant is shown in Fig. 1. From one side a rotating drum with the substrates extends into the ca. 1000 l cylindrical vacuum chamber. From the other side an evaporator unit extends into the chamber that fits into the substrate drum. The drum and evaporator unit, along with the supporting doors, move on rails. The door which supports the evaporator unit and its four boats also contains two hollow cathode sources.

The coating process involves rapidly rotating the substrate drum in order to force the small substrates onto the drum wall by centrifugal force. The substrates are periodically passed over the evaporator as the drum rotates. Using this trick one gets around the problem of subjecting the large number of individual small substrates to the vapor flow which is mainly directed upwards. It must also be guaranteed that the small substrates are coated on all sides, namely they must change their position several times during the process. In the original concept and design a stripper brush was provided for this task and this ensured the small components continually changed position. The design concept was clear and showed much promise.

However during the course of the aforementioned project a multitude of problems manifested themselves. These on the one hand concerned the substrate handling and on the other hand the control of the plasma activation in compact spatial surroundings with various voltage-carrying, earthed and insulating components which could be subjected to undesired electrical contact via the effect of the metallic stray-vapor or via misrouted substrates.

The approval of a follow-up project (“Deposition of aluminum-based functional layers on mass-produced goods via plasma-activated vacuum processes”, ALMAPLAS) allowed the aforementioned problems to be remedied using new design approaches. For example, a capsule aperture which completely surrounded the evaporator unit was designed. Only in the open state does this open windows for the vapor flow, otherwise it shields the unit from the substrates and so prevents short-circuiting due to substrates. In connection with this a large number of shields had to be changed and optimized in order to combat problems associated with the growth of aluminum layers on insulating and also moving parts during the course of the operations. Another significant design change concerned the periodic rearrangement of the substrates by varying the speed of rotation. This allows the stripper brush to be omitted. There is hence no mechanical abrasion of the layer by the stainless steel bristles and there is no need for the tricky determination of the ideal angle of the brush as a function of the substrate geometry, the drum charge and the degree of utilization of the brush.

Fig. 2 shows by way of example the distribution of a mixed charge of copper and steel rivets on the rotating substrate drum. During startup the rivets undergo random movements and are thoroughly mixed and evenly distributed on the drum wall. The ideal charge corresponds to about a monolayer of rivets on the drum, namely about forty thousand rivets or 20 kg of rivets. The base technology involves not only substrate handling and plasma-activated evaporation but also plasma pretreatment of the substrates.

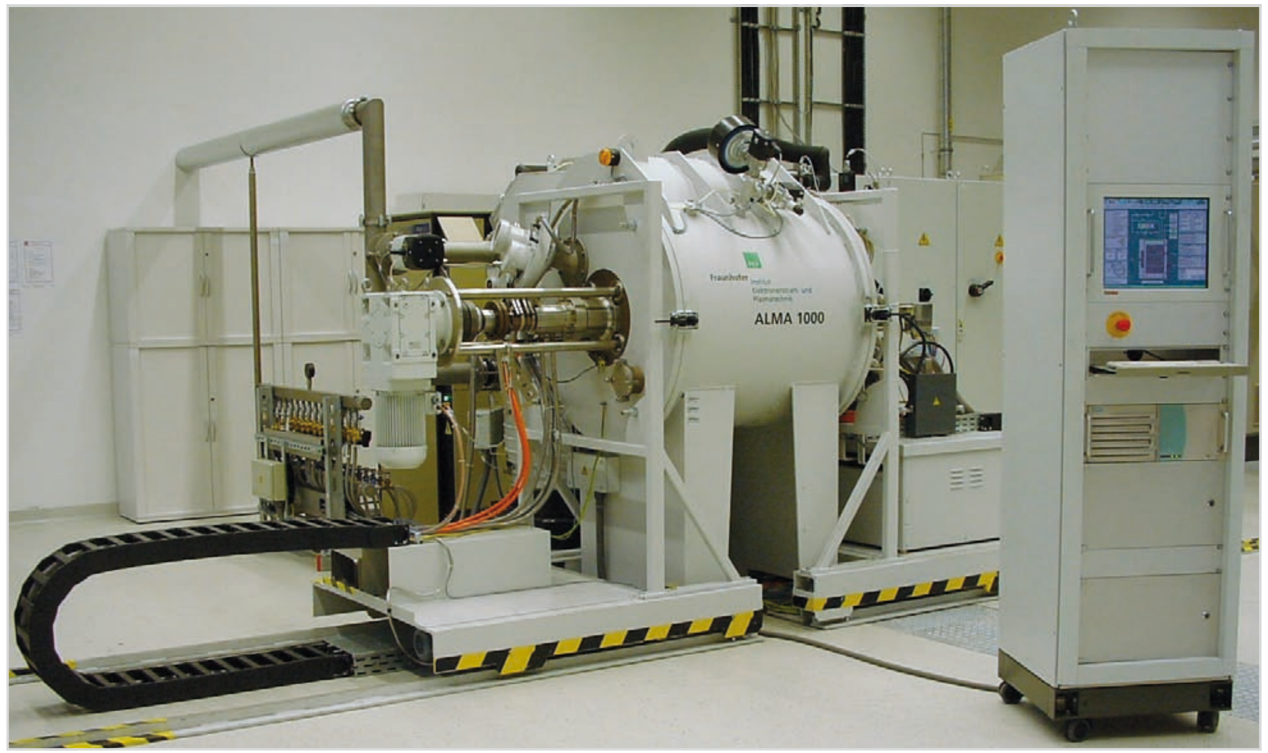


Fig. 1: The ALMA 1000 experimental plant for coating mass-produced products.

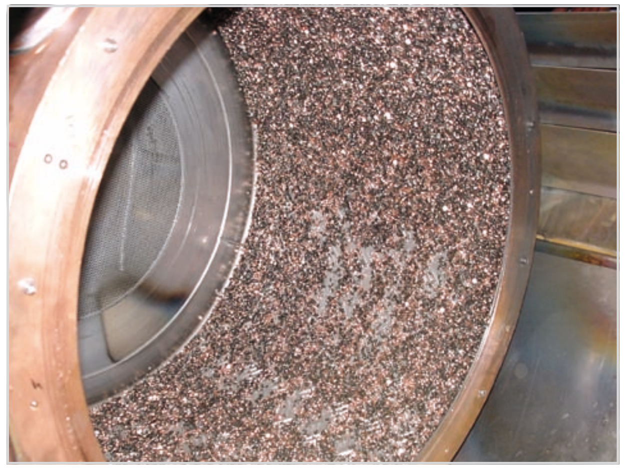


Fig. 2: Distribution of a charge of copper and steel rivets in a rotating drum. There is good mixing of the charge even after just one start-up.

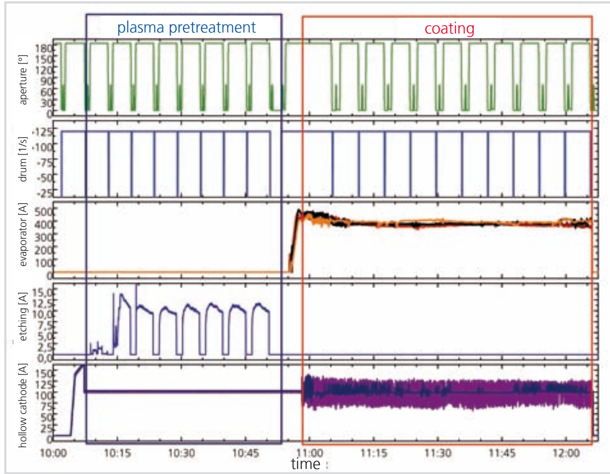


Fig. 3: Time profile of several process parameters during the whole process.

Fig. 4: Fasteners after passing through the coating process.

For this a plasma is generated via the two hollow cathodes and the booster anodes in the evaporator zone. Via pulsed biasing of the substrate drum, the ions in the plasma are used to etch the substrate surfaces and hence provide microscopic cleaning. In tests on copper coated steel sheets an etching rate of > 5 nm per minute of effective etching time was measured. For the charge of rivets it must once again be ensured that the total surface of the rivets is etched, namely the rivets must be repositioned several times in this processing step and the total etching time must be adjusted accordingly.

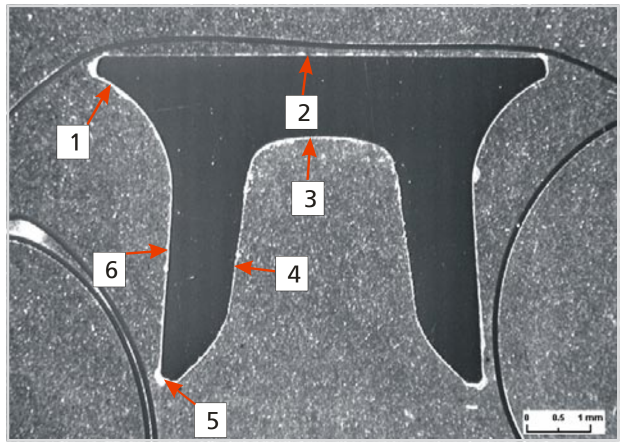
The repositioning of the rivets is effectively achieved by repeated stopping and starting of the substrate drum. Due to the chaotic motion of the substrates these steps must be carried out with a closed aperture. As soon as the substrates are forced against the drum wall the aperture is opened and the substrates are subjected to the effect of the plasma and the vapor. Fig. 3 shows the time profile of the whole process. The aperture angle and the speed of rotation of the drum are adapted to each other such that, with observance of safety intervals, the aperture is only opened when the substrates are completely forced against the drum wall. The different colored lines show the operational status of the hollow cathodes and boat evaporators.

Fig. 4 shows a number of substrates which have passed through the whole process. This was a mixed charge of different fasteners which were coated as a full charge along with dummy substrates. This procedure allowed the operating behavior under practical conditions to be tested and one obtains sample objects which can be analyzed after representative processing. It also allowed substrate-specific peculiarities to be identified which could be put down to the substrate geometry, substrate material or surface texture. In this project the main focus is on the semi-hollow punch rivet, whereby in a single work step a hole is punched in the work piece and the rivet connection is realized. Although the use of rivets, a very old joining technique, has been partially replaced by welding and adhesive bonding technologies over the past decade, there are still application areas where it cannot be replaced by other techniques. Indeed in some areas riveting is even experiencing a renaissance, either due to the special

combination of materials being joined or due to safety reasons. Rivets are mass-produced and many millions of them are used for securely joining components in machines, cars, rail vehicles and aircraft.
The continuous development of new materials and the trend towards using combinations of materials to meet very specific component requirements means that riveted connections are once again growing in importance.
The rivet requirements of one leading German car manufacturer currently amount to about a hundred tons per year, a quantity that can be refined in a production plant with coating costs of less than 5 €/kg. Within the framework of an AiF funded joint project, involving several research institutes and under the supervision of interested industrial companies, entitled "Corrosion tests on coated selfpunching fasteners", punch rivets coated with the described process are being subjected to corrosion tests.
A comparison is also being carried out with competing processes in which, for example, corrosion-resistant layers are applied by wet-chemical means. The first punch rivets coated at the FEP with the described process are currently being tested at the Institute for Corrosion Protection. The results are however not yet available.

Fig. 5 shows a micrograph of a cross-section of a coated rivet. The layer thicknesses at characteristic points on the surface are indicated in the table. These highlight a short-coming which occurs if the process is not optimum: The layer thickness distribution on the rivet surface is very uneven. There is a thickening of the layer on the sides of the rivet due to mechanical processes during movement of the substrate. On the other hand, the layer thickness on the smooth surfaces of the rivet is < 5 µm and probably insufficient. It is assumed that a minimum layer thickness of 5 to 10 µm is necessary to guarantee the required degree of corrosion protection. The coating technology is being optimized further taking into account the results of the coating analysis and corrosion tests. Work is currently focusing on the following aspects:

- Derusting / substrate precleaning before the vacuum process
- Increasing the plasma density and homogenization of the plasma distribution in the substrate area using magnetic fields
- Determination of optimum coating cycles by varying the duration of the coating, the rate of evaporation and the intensity of the plasma activation.



1	40 ... 80 µm	2	5 ... 20 µm	3	1 µm
4	3 µm	5	10 ... 100 µm	6	9 ... 30 µm

Fig. 5: Micrograph of a cross-section of a coated rivet showing the coating thickness at different points on the surface.

Considering the current status of the process development work, successful completion of the ALMAPLAS project is expected within the coming year. Although coating technology has reached a proven and reliable state due to the continuous work that has been put in over recent years, the coated substrates must now prove themselves in corrosion and application tests in order to give manufacturers and end-users of the products the confidence to implement the technology in their production lines.

The FEP is able to supervise customers during the implementation phase and pass on the know-how that has been acquired during the project work. ■

Federal Ministry of Education and Research
AiF Otto von Guericke

Metallization of optical discs – development of a new sputter source at the FEP

Ralf Blüthner

Over the last two decades optical storage media have been an unprecedented success story for digital mass storage. The first such medium was the Compact Disc (CD) which was designed by Philips and Sony for storing digital audio data. In 1980 these companies laid down the standard for audio recordings. CDs were first introduced to the public at the Radio and Television Fair in Berlin in 1981 and on 17th August 1982 the first commercial production of CDs anywhere in the world started in Langenhagen near Hanover. Some six weeks later the first mass produced CD players were available in the marketplace. Just six years later some 100 million audio CDs were being produced annually around the world. In 1994 the so-called CD-R (short for CD-Recordable), a write-once CD developed in Japan, arrived in the marketplace (ca. 15 billion produced globally in 2003). Two years later the CD-RW (short for CD-Recordable-Writable) and DVDs became available, the latter being developed originally for storing digital video data. Then in 2006 came the high definition DVD (HD DVD) and Blu-ray Disc (BD) which can store 200 GB of data (prototype status as per August 2006).

The commercial manufacture of these storage media is nowadays being carried out by globally-operating system suppliers using all-in production lines, namely lines which encompass all the necessary processing steps from pressing the polycarbonate preforms to packaging the end-product. A key step in this series of processes is metallization, the application of a partially or fully reflective metal layer. A prototype of a round sputter-magnetron has been developed at the FEP for carrying out this task. This work was commissioned by a supplier of CD/CD-R/DVD/DVD-R production lines in the low price segment.

Motivation and objective

Despite the gigantic production halls now manufacturing these optical discs, there is intense global competition amongst the plant suppliers and hence very high pressure to innovate.

As part of development work on a new generation of plants, the commissioning party required significantly more efficient metallization. The most common layer materials used are aluminum, silver, special silver alloys and also silicon. In addition to improving the layer thickness distribution, the chief objective of the development work was to increase the working life of the target material several-fold. The set objective was to coat 1.25 million discs with ca. 10 nm thick semi-transparent reflective layers. Analogously, the objective was to coat 250,000 discs with ca. 50 nm thick fully reflective layers. From a design point of view, the task was also to develop a compact sputter source which guarantees very easy and reliable operation.
It was envisaged that longer maintenance cycles and the lowering of production costs due to much better utilization of the target material would prove to be key selling points for the new technology.

Fig. 1: CD preform in the coating station of a metallizer.

Metallization of optical discs – development of a new sputter source at the FEP

Technical solution

The solution was based on previous FEP development work on Magnetic Hard Discs. This also involved the stationary coating of planar substrates of small diameter.

The idea was to use the key advantage of electromagnetic generation of the sputtering magnetic field compared to using permanent magnets. This advantage is that the magnetic field can be controlled very quickly and precisely. As such, the heart of this project concerned development of the magnetic circuit, consisting of a magnet yoke with two individually adjustable coils and other components for guiding the magnetic field to the target surface. The sputtering magnetic field resulting from superimposition of the two coil magnetic fields can be passed across the whole of the target surface by suitable control of the coil currents during each individual substrate coating.

This rapid control of the plasma annulus allows the progressive erosion of the target to be optimized for maximum utilization of the target and simultaneously allows the layer thickness distribution on the substrate to be monitored. The design was based on the modeling results for the magnetic circuit taking into account the strict specifications of the customer with regarding size and interface design. For the special coil control system a modular coil power supply unit (DMCC 05) was developed with an external partner.

The time / coil current profile which is repeated for each coating is defined by a program which contains up to 11 checkpoints (triplets comprising the target values of the two coil currents and the relevant moment in time). Using these checkpoints the DMCC 05 determines the time profile of the coil currents that must be achieved.

The program definition and administration is carried out as part of the higher plant control system.
This division of tasks between the DMCC 05 and the plant control system on the one hand guarantees precise coil current control (down to the millisecond range) and on the other hand allows the opportunity to modify the program on changing the target or product and also during the lifetime of any target. Also envisaged here was the possibility of time-related modification of program parameters after

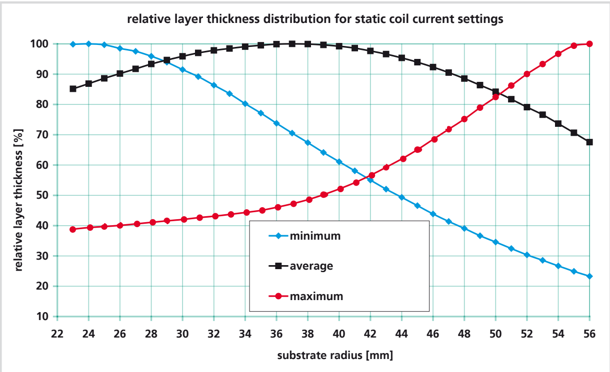


Fig. 2: Relative layer thickness distribution for static coil current settings.

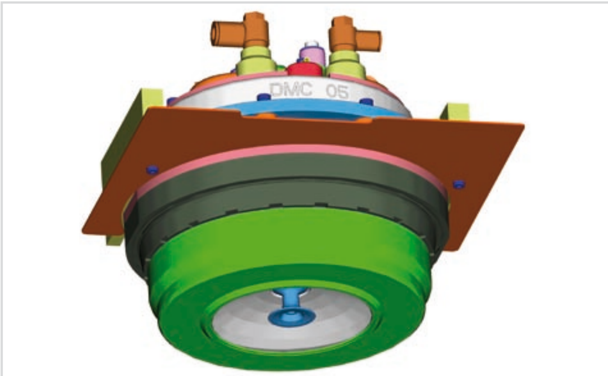


Fig. 3: Schematic 3-D representation of the DMC 05.

Fig. 4: 3-D representation of the sputter target.

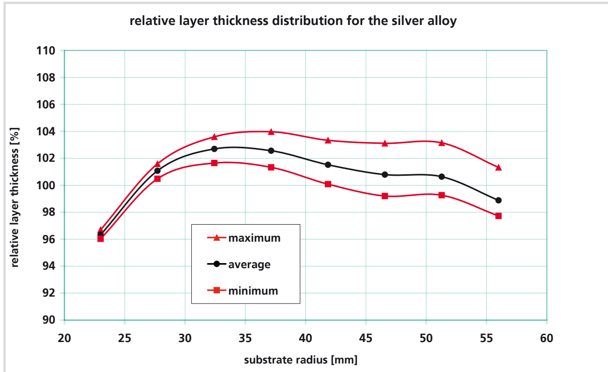


Fig. 5: Relative layer thickness distribution for optimized coil current control.

continuous optical measurement of the layer thickness in order to provide product quality assurance.

In order to attain the desired number of substrate coatings per target, a very high amount of target material is required. This can be achieved in two ways. Firstly, a target diameter was chosen which was considerably greater than the diameter of the CDs and DVDs that were to be metallized. The resulting lowering of the effectiveness of the sputtering process (increasing aperture coating) was combated by using conical targets. Secondly, average target thicknesses of > 30 mm were realized. The target geometry is therefore also a key part of the development work.

Testing and optimization

Following the design and construction of the prototype magnetron, the magnetron was brought into operation, tested and optimized using a customer's own metallizer, which was made available to the FEP for the duration of this work. This enabled near-production conditions to be achieved.
In particular the whole plasma environment, the sputter gas inlet and the sputter power supply have a major influence on the subsequent transferability of the test results.
A rotating table for the substrate was also available, which allows a "real" coating treatment to be undertaken. From the outset the new coil power supply unit (DMCC 05) was connected via the

Profibus interface. During the testing work, the program setting and transfer to the DMCC 05 had already been implemented by our customer into the software of the plant computer.

The actual coil current profiles and the current and voltage profiles of the sputter power supply unit were continuously recorded. Consequently, any control problems were able to be detected and remedied. After the whole sputter system had been taken into operation, work was started to characterize the sputtering process and optimize the layer thickness distribution. Layer thicknesses in the range between 10 and 100 nm were determined using optical transmission measurements. In order to obtain real measurement results, a special measuring system was used similar to that used in production operations for quality control.

In connection within this, the model-based target geometries of the three materials that were studied were optimized. Suitable program parameters for controlling the coil power supply unit when sputtering new targets were also determined.

Naturally the program parameters that were initially used are not optimum for the whole lifetime of the target, rather they must be changed as erosion of the target progresses. The utilization of the target can hence be increased, whilst constant guaranteeing the required layer thickness distribution.
The commissioning party undertook this work themselves based on the results of the development project.

Summary

In just 8 months a prototype sputter magnetron DMC 05 for the stationary coating of optical discs with metallic reflective layers has been developed and tested. The design meets the requirements for the intended use in the low price sector. In particular, the compact and robust technical design coupled with the rapid and efficient operation should be useful features for everyday production.

We have successfully implemented the idea of the plasma ring passing over the whole target surface for each individual substrate coating. The total duration of a coating procedure is only between 0.7 s (semi-transparent layer) and ca. 2.5 s (fully reflective layer). The layer thickness distribution on the substrate is determined by the superimposition of the direction characteristics of all track radii that are covered taking into account the relevant average duration of the plasma ring in the relevant target area. The specified layer thickness distributions were demonstrated on 3 target materials. The necessary precision and speed of the magnetic field control was achieved using a special control unit for the power supply to the two magnetic coils. Additional magnetically active components incorporated into the magnetic circuit play a considerable role in effectively guiding the sputter magnetic field to the target surface. This allows average target thicknesses of over 30 mm. These results mean that the desired high working life of the target can be achieved, for example 1.25 million substrates coated with semi-transparent reflective layers.

Use of reactive pulse magnetron sputtering to deposit Al_2O_3 and SiO_2 layers for electrical insulation applications

Dr. Hagen Bartzsch

Thin layers having high insulation resistance are required for many applications in electronics, sensor technology and photovoltaic technology. These applications include gate oxide layers in microelectronics (which are only a few nanometers thick), insulating layers in sensor applications (where dielectric strengths up to 1000 V can be required) and insulating layers in photovoltaic technology (where the requirements on dielectric strength are lower but where large areas must often have a breakdown free layer).
In addition to having high breakdown field strength, high insulation resistivity and high area yield, other properties are often demanded, for example resistance to high temperature, resistance to aggressive media, a satisfactory mechanical load limit, effective permeation barriers, good adaptation of the coefficients of expansion to the substrate, dielectric strength also in contact with electrolytes, resistance of the layer in downstream processing steps such as laser trimming or wet-chemical etching processes. The coating costs must also be in reasonable proportion to the value of the end-product, meaning that there is often a demand for high deposition rates.

The chemical vapor deposition processes (CVD and PECVD) are the most established processes for manufacturing such insulation layers. The advantages of these processes are the high deposition rates and good insulation properties that are achieved. Some of these layers, however, have shortcomings regarding their mechanical properties, temperature resistance and permeation barrier properties. RF magnetron sputtering on the other hand allows very effective insulation layers to be deposited, albeit at relatively low deposition rates. This article describes the use of reactive pulsed magnetron sputtering in the stationary mode to manufacture insulating layers. Due to the high deposition rates that can be achieved, this process is especially suitable for producing thick layers where very high dielectric strength is required.

Deposition of Al_2O_3 and SiO_2 layers

The deposition of Al_2O_3 and SiO_2 insulation layers was carried out by stationary coating in a cluster sputtering plant using the double ring magnetron DRM 400

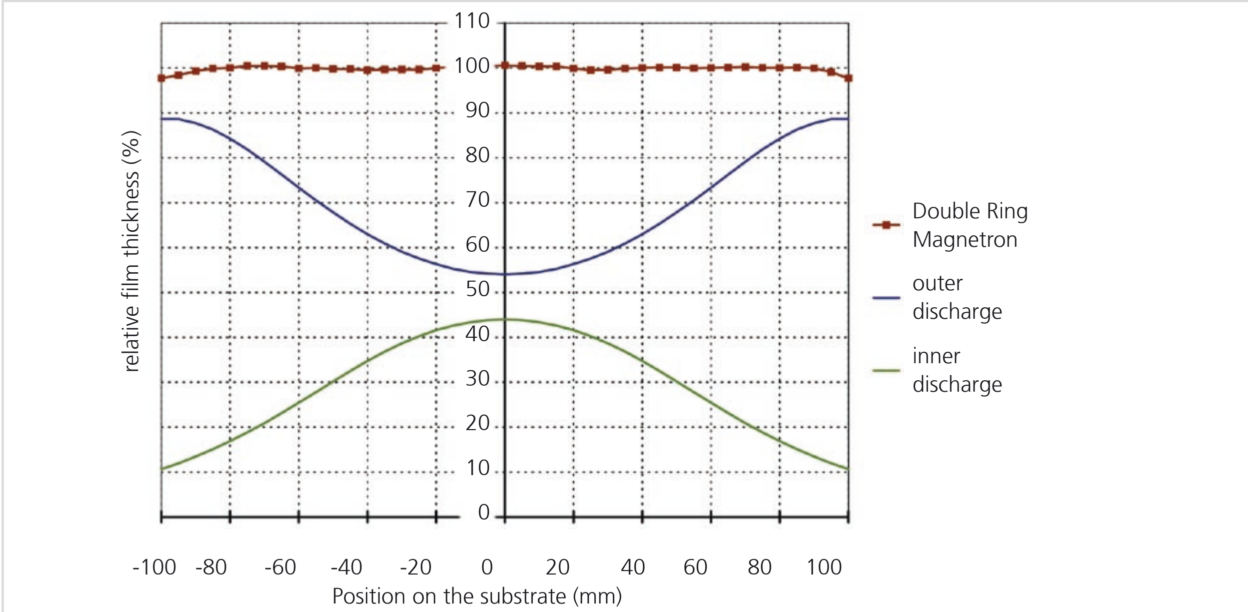


Fig. 1: Layer thickness distribution of the double ring magnetron DRM 400, resulting from superimposition of the contributions of the inner and outer discharges.

Use of reactive pulsed magnetron sputtering to deposit Al_2O_3 and SiO_2 layers for electrical insulation applications

developed at the FEP [1]. This magnetron allows the deposition of homogenous layers on substrates having diameters up to 200 mm by superimposition of the layer thickness distributions from two concentric discharges (Fig. 1).

The deposition of insulating layers using this magnetron can on the one hand be achieved by RF magnetron sputtering (13.56 MHz) from the insulating target. Reactive sputtering, however, allows considerably higher deposition rates, whereby sputtering occurs from a metallic target (e.g. Al) and the formation of a layer on the substrate, in our case Al_2O_3, is effected by admitting a reactive gas (e.g. O_2). The long-term stability and the high deposition rate of this process are guaranteed by energy supply in the pulsed mode (20 ... 300 kHz) and suitable control of the flow of the reactive gas. Table 1 shows examples of different insulation and barrier layers and the deposition rates that can be achieved.

The energy supply in the pulsed mode was achieved using the UBS-C2 electronic pulse unit developed at the FEP and two different operational variants were employed (Fig. 2). Unipolar operation of the DRM 400 involved applying a pulsed voltage between the two targets and the common anode. This is designed as a so-called hidden anode, which is protected against being coated with insulating reaction products and is therefore continuously active. Bipolar pulsed operation involved applying a voltage of alternating polarity between the inner and outer targets of the DRM 400. The two targets act alternately as the cathode and anode of the magnetron discharge and therefore require no separate anode.

Layer	Rate [nm/sec]
Al_2O_3	2.5
AlN	2
SiO_2	6
Si_3N_4	2
Ta_2O_5	2

Table 1: Deposition rates for insulation layers and barrier layers.

Studies have demonstrated that there are considerable differences between the energy supply variants with regard to the bombardment with high-energy electrons and ions in the plasma. Table 2 compares the measured values for the thermal substrate load, which is chiefly caused by bombardment with high-energy particles.

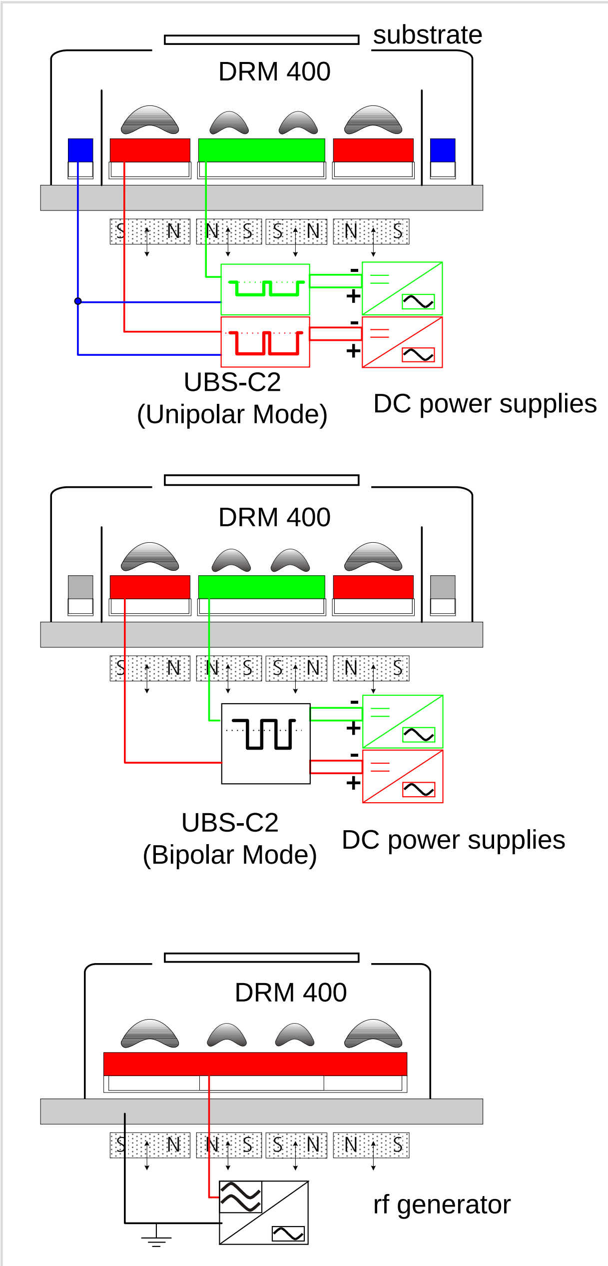


Fig. 2: Energy supply variants for depositing insulation layers: a) unipolar pulse mode, b) bipolar pulse mode, c) RF magnetron sputtering.

In the bipolar mode there is considerably greater substrate load than in the unipolar mode. The cause is the expansion of areas of high plasma density towards the substrate in the bipolar mode [2]. Using the RF mode at equivalent power the substrate load lies between the values for the unipolar and bipolar modes. If the substrate load is ratioed against the deposition rate then for RF mode it lies significantly above the values for both the unipolar and bipolar modes.

Electric insulation properties of Al_2O_3 and SiO_2 layers

In order to determine the electrical resistivity and breakdown field strength, Si-wafers were coated with Al_2O_3 or SiO_2. For contact, aluminum electrodes having an area of 12.5 mm² were sputtered onto the surface. The current between the electrode and wafer on applying a DC voltage was measured.
The resistivity was determined at a voltage of 400 V and the breakdown field strength on exceeding a current density of 1 µA/cm² was determined. Table 2 gives the measurement values for the different production methods.
For SiO_2 coatings the data show that layers deposited via RF sputtering and bipolar pulsed sputtering had better insulation properties (in particular regarding the insulation resistivity) than the layers deposited in the unipolar mode. The more energetically intense substrate bombardment in the bipolar mode and for RF energy supply, as described in the previous section, favors the deposition of dense layers having advantageous insulation properties. The comparison also shows the layers deposited in the bipolar pulsed mode at a 23-fold rate have virtually identical insulation properties to the layers deposited using conventional RF sputtering.
The Al_2O_3 layers deposited via pulsed sputtering also have high resistivity and a high breakdown field strength, with the layers deposited in the unipolar pulsed mode having somewhat higher values. The breakdown field strengths of 5 ... 8 MV/cm measured for the Al_2O_3 and SiO_2 layers correspond to typical literature values for good insulating layers (see [3] and [4]), although measurements reported in the literature mostly relate to very much smaller electrode areas between 0.01 and 0.5 mm².

Applications

Due to the high coating rate and ability to coat high areas, reactive pulsed sputtering is especially suitable for depositing thick layers having high insulation voltages and for coating large components or large numbers of work pieces. One example of an application concerns electrical insulating layers for pressure sensors in metal technology (Fig. 3). In these sensors a pressure change causes deformation of a metal membrane. The resulting change in length and hence change in resistivity of a resistance layer is evaluated electrically. Between the metal membrane and the resistance layer there is an electrical insulation layer, with a dielectric strength of up to 800 V and an resistivity > 10^{10} Ω/cm² being required for this.

Such insulation layers are traditionally manufactured by RF sputtering or CVD processes. In conjunction with Siegert TFT in Hermsdorf, a manufacturer of pressure sensors, a process has been developed at the FEP for depositing insulation layers using reactive pulsed sputtering. In addition to ensuring the insulation strength of the layers, a series of other properties such as adhesion strength, laser writabilty and stability under thermo-mechanical stress had to be guaranteed. Following successful qualification of the insulation layers and verification of the reproducibility of the results in several coating series, the industrial partner is now transferring the process to large-scale production of pressure sensors. For this, a cluster sputtering plant is

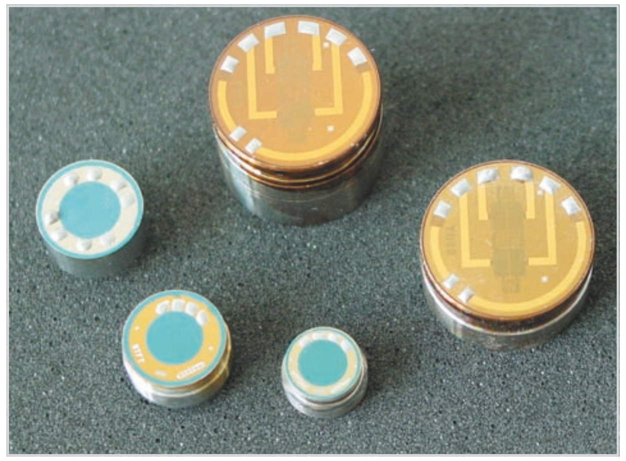


Fig. 3: Pressure sensors with an electrical insulation layer and resistivity measurement structures ©SIEGERT TFT GmbH.

currently being built in collaboration with VON ARDENNE Anlagentechnik (VAAT), the plant construction company. In this project the FEP is responsible for the technology for depositing Al_2O_3, SiO_2 and Si_3N_4 via reactive pulsed sputtering and is making available the process technology based on the double ring magnetron DRM 400.

Summary

Al_2O_3 and SiO_2 layers deposited using reactive puls-magnetron sputtering possess excellent electrical insulation properties. Due to the high productivity of this technology it is particularly suited for depositing thick insulation layers and also for coating large areas and for coating large numbers of work pieces. The implementation of this process for the industrial production of pressure sensors is planned for 2007. Other applications in the area of medical technology, electronics and sensory technology are under development. ■

Acknowledgement

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Federal Ministry of Economics and Technology

AiF Otto von Guericke

PRO INNO II

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Material	Deposition method	Deposition rate [nm/min]	Thermal Substrate load at 1 kW sputter power [W/cm²]	Specific resistivity ρ [Ω·cm]	Breakdown field strength [MV/cm]
SiO_2	Unipolar pulse mode	400	0.02	3.2×10^{15}	6.2
SiO_2	Bipolar pulse mode	350	0.1	6.3×10^{16}	7.6
SiO_2	RF magnetron sputtering	15	0.06	1.3×10^{17}	8.7
Al_2O_3	Unipolar pulse mode	150	0.03	2.3×10^{16}	6.2
Al_2O_3	Bipolar pulse mode	100	0.11	2.0×10^{16}	5.1

Table 2: Properties of Al_2O_3 and SiO_2 layers for applications as electrical insulation layers; the electrical properties were measured on an electrode area of 12 mm^2.

ELEWER – An established network

The regional communication and technology platform ELEWER is being utilized by an ever larger circle of interested parties. Of the 78 current members some 67 are from industry. The supra-regional and international reputation of the network has grown considerably and is of special importance. The opportunity for knowledge transfer and experience exchange on issues relating to electron beam technology is being welcomingly taken up. Again and again interesting innovative approaches are being found for solving actual problems. New uses for electron beam technology are in particular being found in the area of non-thermal electron beam applications. Therefore there is a special demand for communication and collaboration in this field.

Activities

During the course of the year network members have facilitated contact between company representatives and experts in electron beam technology. The network was represented at the Hungarian-Saxon Commerce Day in June 2006 in Budapest by the network manager and was also represented by members at other technical events. As a result of the contacts that were made, potential joint research projects and strategies were conceived. The highlight of the network's work was once again the now traditional Dresden Symposium for Electron Beam Technology. The 2006 symposium, the fifth time this event has been held, was entitled "Innovative polymer materials via electron treatment". The Leibniz-Institut für Polymerforschung Dresden e. V. (IPF), a member of the ELEWER network, organized the event and invited many participants.

Results

The 5th Dresden Symposium for Electron Beam Technology was attended by more than 90 people from industry, research and development. Interested parties came from diverse sectors of industry and they utilized the opportunity to learn about the latest results and to learn about the experiences of established users of electron beam technology from R&D and from professional suppliers of electron beam technology. In addition to the many German participants there were 5 participants from other EU countries and a representative of an American firm. A survey of the participants emphasized the importance of such an event and it was highly recommended to continue this traditional symposium in the future. The topics for future symposia will be chosen from the results of the survey and will include the following key areas:

- Properties of modified surfaces
- In-line sterilization
- Functionalization of surfaces
- Experience of practical applications in industry

This simultaneously creates a platform for exchanging knowledge and experience regarding ongoing ELEWER projects. Irregardless of this the boundary conditions of project partners will naturally be respected in the future in the interests of the relevant competitive situation. Where necessary there will be confidential treatment of the project content and the results that are achieved.

The ELEWER network can be satisfied with its achievements to date. Warm thanks at this point go to all those involved. In the future the FEP will continue to support all activities which lead to further strengthening of the field of electron beam technology in both the regional and international marketplace. ■

Application of electron beam technology for ultra-fast tomography of multiphase flows

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Multiphase flows are flowing mixtures of substances in different states of matter. They are present in cooling circuits of nuclear power plants, in processing plants and chemical reactors, in bioreactors, in conveying and transport systems for liquids and bulk goods, in hydraulic, cooling, heating and wastewater systems and in heat exchangers and desalination plants. There is therefore considerable demand for methods that can measure the distribution of the relevant phases inside such plants. In a number of sectors of industry there are very practical issues directly related to the features and behavior of multiphase flows. Worthy of mention, for example, is the oil production sector, where it is necessary to measure the flow right at the bore hole for fiscal determination of the amount of oil that has been recovered.

There is still a need here for a robust measuring technique which can be used under extreme conditions, for example oil production in deep seas, and which has a volume accuracy of better than 1% for measuring the oil fraction in mixed flows. The latter typically comprise crude oil, gas, water and solids materials in suspension. A second example worthy of mention is nuclear technology. Here the manufacturers of fuel elements are chiefly interested in the flow processes within the fuel element bundles under near-reactor conditions, namely at operating pressures of more than 5 MPa and saturation temperatures of water above 250°C. The two-phase flow here determines the efficiency of the heat transport from the fuel rods to the coolant and is hence very important for both the performance and also the operating safety of a nuclear plant.

The operating behavior of fuel elements is nowadays tested in thermohydraulic test plants without the use of nuclear fuel. There is however still no method available for visualizing the flow. Besides these industrial issues, there is also increased scientific interest in acquiring reliable measurement data on multiphase flows. This is due to the growing trend towards simulating flow processes as part of design, optimization and safety assessment in nuclear technology, chemical technology and biotechnology, in the oil industry, shipping industry and aircraft and aerospace industries and in the construction of turbomachinery. As the so-called Computational Fluid Dynamic Codes still have shortcomings for simulating multiphase flows, measurement data are required for both code validation and also model development.

Computer tomography (CT) based on x-rays and gamma rays is an attractive technique for analyzing multiphase flows. Measurement is contact-free and hence has no effect on the flow. The irradiation allows views into non-transparent vessels and penetrates turbid and non-transparent fluids, suspensions, emulsions and solid layers without a problem. As the propagation of the radiation is linear, it is possible to obtain sharp images of hidden structures.

Up until now computer tomography has been mainly used as an imaging technique in medicine and for the non-destructive testing of materials. For some time though there have been various international efforts to make computer tomography methods available for studying multiphase flows. A problem of classical CT scanners for this application concerns the standard recording times. On a medical CT scanner the images are taken using a measurement system which rotates around the patient. This measurement system comprises an x-ray tube and x-ray detector with the relevant electronics. During the rotation of this recording device, radiographic projections of the object are recorded from many angles, normally up to 1000 per revolution. After a full rotation these can be converted by a mathematical algorithm on a computer into a cross-sectional image, which represents the 2-dimensional distribution of the x-ray extinction coefficient in the cross-section under study.

The x-ray extinction coefficient is determined by the density and the atomic number of the irradiated material. This means, for example, that the internal organs of the human body can be displayed with a spatial resolution of about half a millimeter superimposition-free due to their different density and chemical composition. Due to the mechanical rotation of the relatively mass-rich source-detector assembly, recording times of maximum two images per second are possible. This would be too few for studying moving objects, such as flows in industry.
Back in the 1980s work was undertaken to solve this problem with the invention of the electron beam tomograph. This device was specially developed for cardio-imaging and allowed visualization of dynamic processes in the beating heart with an image frequency of up to 50 images per second.

An electron beam CT scanner functions differently to a conventional CT scanner. In the electron beam CT scanner an electron beam emitted from an electron gun is targeted at a massive tungsten target, over a distance of more than a meter inside an evacuated tube. The target surrounds the patient, who lies above the beam tube. Due to electromagnetic deflection of the inertia-free electron beam a rapidly changing x-ray focal spot is generated on the target which now allows the recording of projections at very high frequency. A fixed-positioned x-ray detector is used to measure the radiation passing through the patients.

The principle of electron beam tomography is suitable for studying rapid flow processes. It is however necessary to increase the imaging rate of such a CT scanner to at least 1000 images per second, namely far higher than the standard rate of 50 images per second used for cardio-imaging.

On account of the quantum limitation of the x-ray emission process at manageable generator and target losses of several hundred kilowatts, compromises must be made regarding the object diameter (effect of the inverse square law) and the material composition of the object (effect of the extinction law). Estimates indicate that with a beam generator of 10 kW beam power and 150 kV acceleration voltage, which are typical for electron beam processing technology, tomographic recording at imaging rates above 1000 images per second is possible on objects of size up to 20 cm diameter made of materials of low atomic number such as plastics, aluminum and titanium. For larger objects the beam generator power must be increased by the cube of the maximum source-

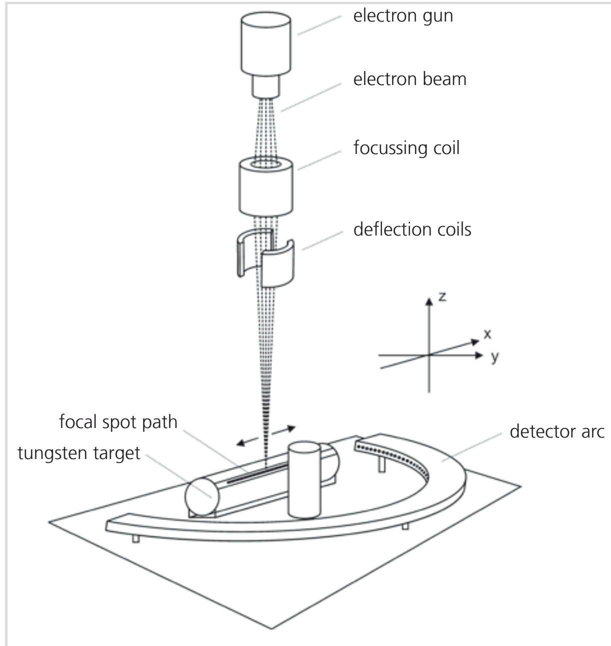


Fig. 1: Schematic representation of the first experimental set-up for ultra-fast electron beam tomography.

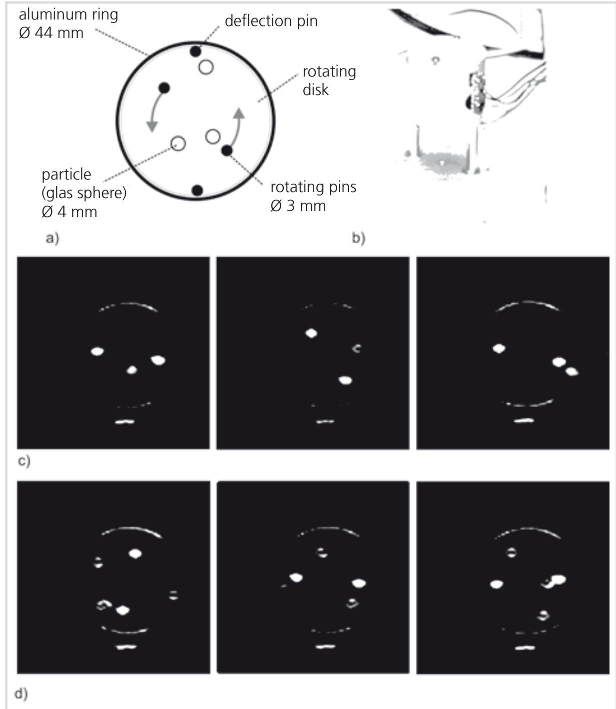


Fig. 2: Glass sphere phantom for demonstrating the visualization of chaotic particle motion in a container (top) and momentary cross-sectional images at an image frequency of 1 kHz for one glass sphere (c) and three glass spheres (d).

Application of electron beam technology for ultra-fast tomography of multiphase flows

Fig. 3: Generator head with x-ray detector (left) and operating console (right) of the new electron beam tomograph.

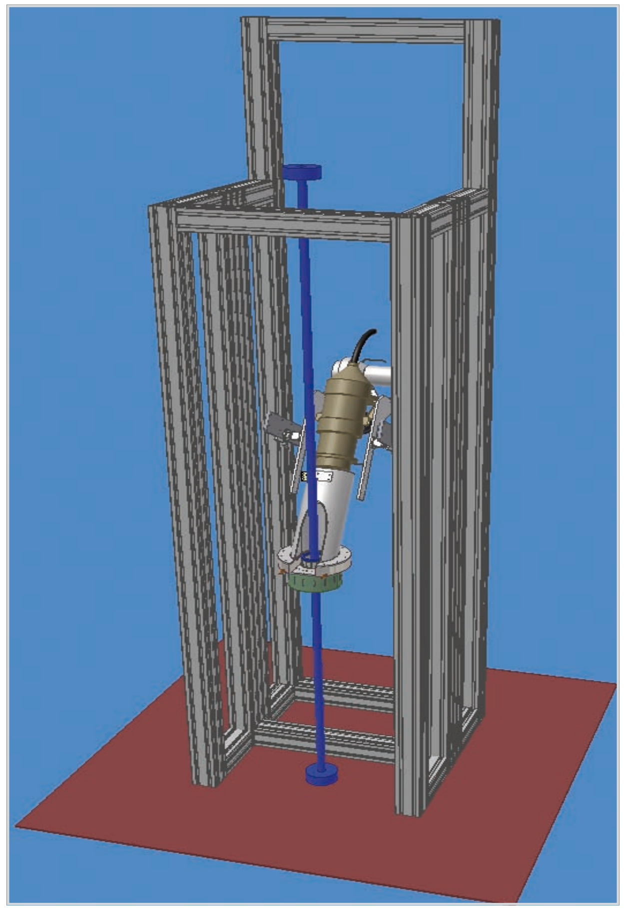


Fig. 4: View of the prospective arrangement of the electron beam tomograph on a vertical pipe section on the TOPFLOW multipurpose thermohydraulic test plant in Dresden-Rossendorf.

detector distance in order to achieve the same image quality. In order to penetrate construction materials having higher atomic number such as steel, it is necessary to increase the energy of the x-rays and hence increase the acceleration voltage to values above 500 kV.

Work is currently ongoing at the Institute for Safety Technology at the Forschungszentrum Dresden-Rossendorf e. V. to make electron beam tomography available as an analytical tool for studying two-phase flows in respect of the safety and operating behavior of nuclear plants and for the purpose of developing and validating two-phase CFD codes. The fundamental viability of the process for studying tubular flow was first of all demonstrated in a series of key experiments. Fig. 1 shows a schematic representation of an experimental set-up for ultra-fast electron beam CT which was tested in this configuration at the Institute for Nuclear Energetics and Energy Systems at the University of Stuttgart in a commercial electron beam welding plant. An elongated molybdenum block served as the target onto which the electron beam was deflected with a maximum of 10 kHz across a scan width of ca. 12 cm.

The x-ray detector arc is constructed around the block. Its 240 active elements are configured at the height of the focal spot path and so define the irradiation plane. A variety of static or dynamic phantoms can be positioned between the target and detector. The glass sphere phantom (shown in the top part of Fig. 2) was designed for portraying chaotic particle motion in a container. It consists of an aluminum beaker which contains glass spheres of 4 mm diameter, which are subjected to random motion by means of a rotating disc bearing two steel pins and turning at 8 revolutions per second.
The lower part of Fig. 2 shows selected reconstructed cross-sectional images from image sequences recorded at 1000 Hz. The particle motion is clearly discernible. The non-optimal scan geometry, which is especially disadvantageous here due to the limited recording angle arising from the linear focal spot path, results in minor image artifacts in the form of distortion on the outer edges of the objects.

The development of an optimized ultra-fast electron beam CT scanner with own electron beam generator and semicircular target geometry means that the next step towards a universally applicable electron beam CT for studying flow phenomena has been successfully completed at the Forschungszentrum Dresden-Rossendorf e. V. The electron beam generator (Figure 5) had originally been developed at the Fraunhofer FEP for electron beam treatment of surfaces. Of special benefit for the tomography application is the large deflection angle of the generator (maximum ca. 18°). It is therefore possible to arrange the target at a relatively small distance from the beam generator, meaning that the scanner is relatively compact.

The beam generator permits a maximum accelerating voltage of 150 kV and a beam current of 65 mA. It has an x-y deflection with maximum 10 kHz deflection frequency. The attainable focal spot diameter is below 1 mm. The target is designed as a 240° ring and is manufactured from graphite and tungsten. The x-ray detector was specially developed. It has more than 240 CZT semiconductor detectors arranged in a circle in the measuring plane and this gives an active surface of 1.5 mm x 1.5 mm. The electronics allow completely parallel sampling of the detector signals of up to 1 megasample per second on all detectors. The measurement values are stored in a local buffer (4 Gbytes) and at the end of the measuring sequence are transferred by USB interface to the system computer.

The scanner and detector are controlled by specially developed control software on a computer in the operating console (Fig. 3). The recorded measurement data are converted to cross-sectional images by tomography software developed by the Forschungszentrum Dresden-Rossendorf e. V. Due to the conventional recording geometry akin to fourth generation scanners, classical reconstruction algorithms such as the method of filtered back-projection can be used.

The construction of the electron beam tomograph represents a milestone on the road to application of ultra-fast x-ray imaging for studying multiphase flow.

In the near future this analytical method will be employed to study water / water vapor flow in a pipe of 50 mm internal diameter. These studies will be carried out using the TOPFLOW multipurpose thermohydraulic test plant at the Forschungszentrum Dresden-Rossendorf e. V. ■

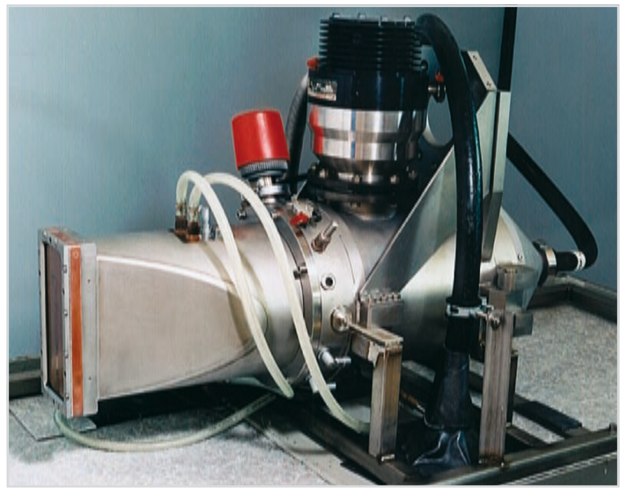


Fig. 5: Electron beam generator (10 kW / 150 kV) of the FEP used in the electron beam tomograph on the test stand.

Sterilization of products with accelerated electrons

Rainer Bartel

In modern society sterile materials and products are being increasingly needed in order to fulfill strict hygiene and cleanliness requirements. Examples of this are disposable medical products such as surgical instruments, bandages, tube systems, etc. and also packaging for pharmaceutical products and foods. Special applications in products such as implants, medicines and raw materials are growing in importance. A method that is already established in a variety of areas is sterilization using accelerated electrons. This is a recognized and standardized method for treatment with ionizing radiation (see, for example, ISO 11137 & EN 552). The sterilization process involves exposing the product to the effect of the accelerated electrons. The energy that is so introduced considerably affects the results. This energy that is introduced is described by the absorbed dose, namely the amount of radiation energy that is input per mass of product. This is expressed in grays (Gy).

The lethal effect of accelerated electrons is due to ionization and the associated changes in molecular structure, whereby cell division and hence further propagation of the micro-organisms is prevented. Compared to thermal methods that have been hitherto employed, the use of accelerated electrons for sterilization involves negligible heating of the product. No chemical agents or sterilization agents are required. Chemical methods are being increasingly restricted due to possible side-effects and thermal methods only have limited use for sensitive materials due to the thermal exposure.

Up until now treatment methods based on accelerated electrons have involved large technical equipment which was totally unsuitable for integration into production processes and was also unattractive from an economic point of view. Modern production and packaging processes however often require in-line sterilization of the products or packaging. There is therefore a current need to develop new efficient approaches for in-line sterilization processes. In addition to sterilization methods, methods for germ reduction and disinfection are also of interest. In the past the FEP has developed key solutions for the use of accelerated electrons in sterilization processes and these solutions have been able to be integrated into production processes. This has involved beam generation systems in the so-called low energy region and modified technology concepts. This low energy technology has the advantage of uncomplicated measures for x-ray shielding and compact construction. The electron penetration depth into the product is up to 0.5 mm and this suffices for most sterilization tasks. Where, for example, compact products, instruments or packaging materials have only to be sterilized on the outside, then low energy technology can be successfully employed. This is the case for many applications, for example in medical technology, in the pharmaceutical industry and in the packaging industry.

Collaboration between Robert Bosch GmbH (work group: pharmaceutical packaging) and the FEP in Dresden has recently resulted in a new technology for external sterilization of packaging for prefilled syringes. The sealed tubs contain syringe bodies and are pre-sterilized. Before the tubs are transported into the sterile area of the filling machine and before the tubs are opened, the whole external surface of the tubs must be sterilized. This is now carried out in-line in an electron beam sterilization process. The new system from Bosch is called Advance-BEAM and its features are ultra high process safety, compact construction and low maintenance requirements. The key advantage of Advance-BEAM is however that the system employs electron generators which emit beams whose doses are adapted precisely to the surfaces of the tubs that are to be sterilized.

A positive side-effect is the 50% lower space requirements compared to equipment that has been available up until now. The total weight is also considerably less. Due to optimum beam guidance a high electron yield is guaranteed and undesired side-effects such as ozone formation and the emission of x-rays are reduced to a minimum. The development of this technology means that the increasing demand for prefilled syringes for administering many medicines such as heparin, numerous vaccines and also special bio-technological products can be met. For doctors and patients, life without these syringes is now unimaginable.

Involvement with this development work has allowed the FEP to continue in a traditional area of its work. In recent years a milestone in the area of sterilization / disinfection was the development of a method to treat seed products with electrons. The e-ventus® technology which was developed in conjunction with Schmidt-Seeger AG has now been successfully used for a number of years in the agricultural sector. This technology is efficient, reproducible and is favorable in cost for users. Long-term analysis of the operating conditions has allowed detailed objectives to be set for further development work. New precisely adapted solutions for the market are being worked on and in the near future this will allow the processing of a wide range of different bulk products, from plastics to fine seeds. Currently a variety of commercially available electron beam systems and also self-developed systems are in use at the FEP. These are used for processes such as germ reduction, disinfection / sterilization and other applications. The FEP possesses detailed know-how about the technology, functionality and efficiency of the most important systems and about technical issues regarding a wide range of applications.

As such the FEP's project partners have access to sound concepts and underpinned solutions which are customized for each particular application. For users the FEP is an expert partner for product-specific development, the development and realization of customized plants and the transfer of electron beam technologies to production. ■

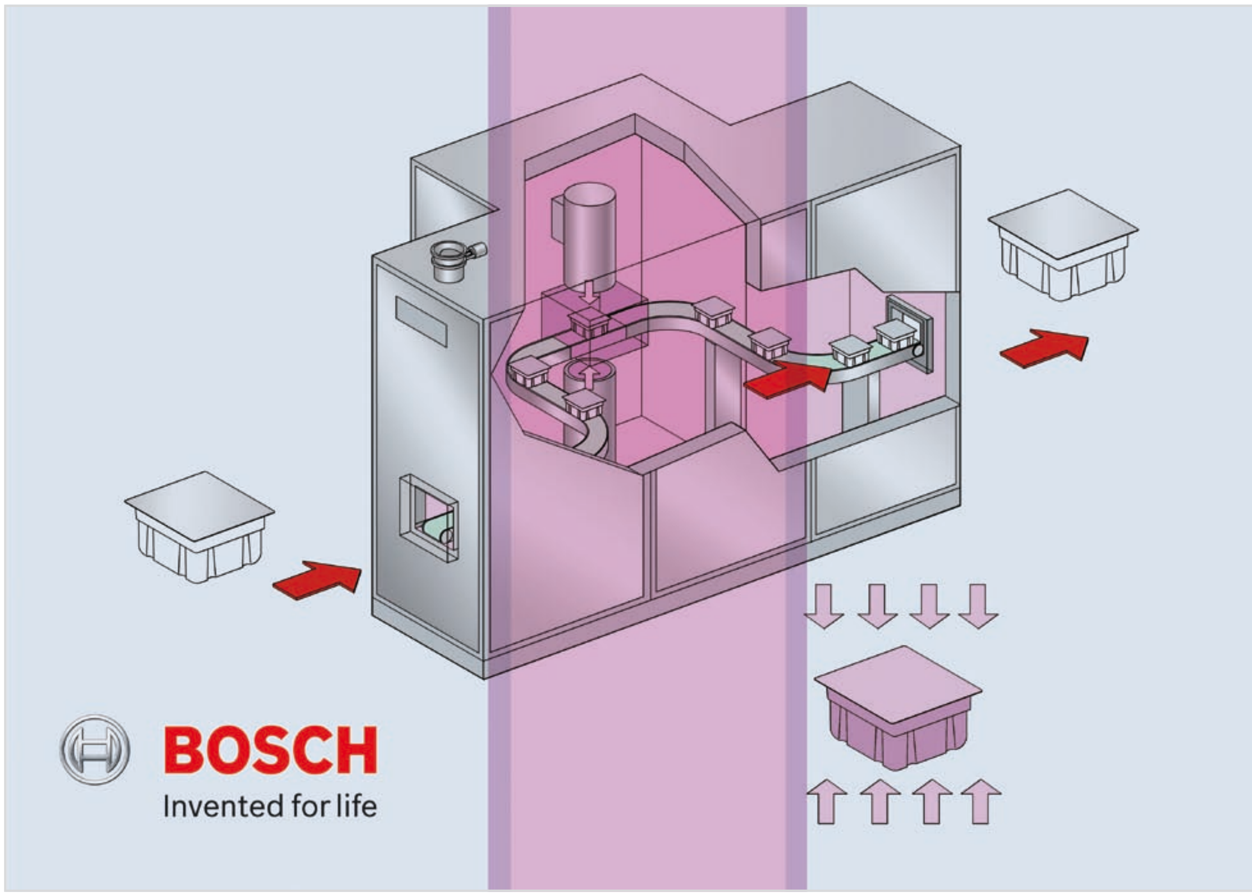


Fig. 1: Advance-BEAM, the innovative electron beam sterilization system from Bosch (Source: Robert Bosch GmbH).

Highlights

Award of the FEP service medal to deserving pioneers

The FEP has paid tribute to the exceptional services of three persons during the initial founding and development of the institute by awarding them the FEP service medal. This is the first time that official tribute has been made to those involved in the founding and early development of the FEP. The medals were presented on 20th September 2006 to Prof. Dr. Siegfried Schiller, Dr. Alfred Hauff and Dr. Hans-Ulrich Wiese during a meeting of FEP employees. The services of these three gentlemen were summarized by Prof. Günter Bräuer, the director of the FEP, in a short address.

Prof. Schiller enthusiastically promoted the founding and early development of the FEP. Using all available influence and means he set the institute's course and hence ensured the continuation of work in the area of electron beam and plasma technology in Saxony. It is due to his initial endeavors that the FEP has been able to develop into an institute of worldwide renown. His many years of experience in science coupled with his clear understanding of the requirements of industry paved the way for today's application-orientated approach of FEP employees. Partly as a result of this, the name of Prof. Schiller will remain associated with the FEP.

Very early on Dr. Hauff recognized the potential of electron beam and plasma technology for future technological developments. As a result of his work for the FEP this expertise was secured for Saxony. As an expert technical advisor and chairman of the FEP committee for many years he steered the development of the institute along a successful path. The fact that the FEP is today able to successfully operate its business fields in a global marketplace is due in no small part to Dr. Hauff.

As a board member of the Fraunhofer-Gesellschaft, Dr. Wiese was responsible for shaping the development of the FEP in a decisive way. His guidance was crucial during the founding of the institute and during the structuring and organization of the FEP. In addition, his many years on the FEP committee were of key importance for the strategic development of the institute. As a result of his active support the FEP was able to develop in a stable and positive way. The institute can now look back on a successful past and this is not least due to the efforts of Dr. Wiese.

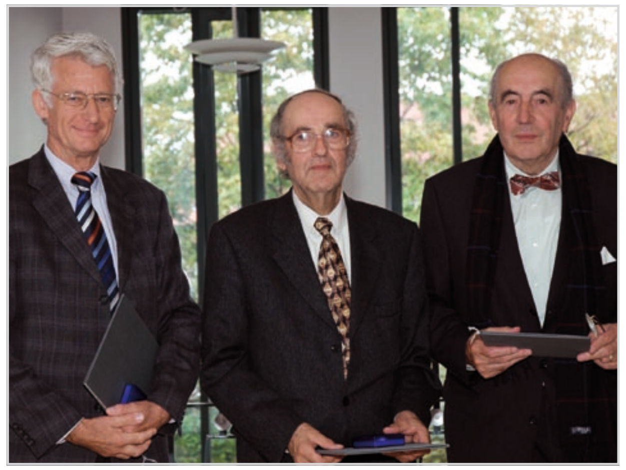
After the medals had been awarded, Prof. Kirchhoff gave an overview of the current work of the FEP. In addition to the main scientific and technological areas of work, collaboration with companies and training establishments in Saxony was singled out. In addition to the work of Prof. Schultheiß at the Institute for Solid-State Electronics at TU Dresden, Prof. Kirchhoff has promoted collaboration with the Westsächsische Hochschule Zwickau and the Hochschule für Technik und Wirtschaft Dresden. Both these technical colleges use this collaboration to pass on FEP knowledge and know-how to students on different courses.

The students have the opportunity to carry out their practical training and dissertation work at FEP. They hence acquire insight into the latest technologies in the area of electron beam and plasma technology and their diverse applications. This knowledge is beneficial for their subsequent professional work. For the FEP this collaboration also offers the opportunity to attract prospective future employees from amongst the students. With regard to specific R&D work we have a number of collaborative agreements with other organizations in Saxony. These include the Technical University of Chemnitz (TUC) and the Leibniz-Institut für Polymerforschung Dresden e. V. (IPF). Both these organizations are expert partners of the FEP in the area of surface and boundary layer technologies and the treatment of polymers with electrons.

It is envisaged that the number of collaborative work agreements will grow in the future.

The ELEWER network ("The electron beam as a tool"), whose chairman is Prof. Kirchhoff, is an active communication platform which contributes to this collaboration in a special way. It is a network of contacts between technical colleges and companies which links current projects and assignments. It so gives industry access to current research results, enabling the results to be used directly for product development and production.

Ever since the founding of the FEP a key objective of the institute has been to promote regional collaboration. The first three recipients of the FEP service medal realized the importance of this at the outset. The institute will continue to put great emphasis on this collaboration.



6th International Conference on Coatings on Glass and Plastics in Dresden

A highlight of 2006 for the Fraunhofer FEP was the "6th International Conference on Coatings on Glass and Plastics" which was held in Dresden for the first time. This biannual conference first took place in 1996 and has been very successful. In the past the conference has been held in Saarbrücken, Maastricht and Braunschweig. The founders include the current chairman Prof. Dr. H.-K. Pulker (University of Innsbruck), the conference secretary Dr. K. Suzuki (SurfTech Transnational) and the editorial chairman Prof. Dr. M. A. Aegerter (INM Saarbrücken). In July 2004 the scientific committee asked the Fraunhofer FEP to organize the ICCG 2006.

Glass manufacture, glass processing and glass coating have a long tradition in Saxony. Way back in 1973 the then "Research Institute Manfred von Ardenne", the forerunner of the Fraunhofer FEP which was founded in 1992, developed the first plant for the vacuum coating of architectural glass. More than 300 years ago Count Ehrenfried Walther von Tschirnhaus (1651-1708), who was born in Kießlingswalde near Görlitz, founded the first Saxon glassworks. Tschirnhaus is best known as the inventor of the first large burning-mirror. His work on glass casting and high-quality surface treatments also enabled him to manufacture large burning-glasses and twin lens systems. The application of these optical tools for other work on glass and ceramics manufacture ultimately led to the discovery of European hard porcelain.

The PR team at the Fraunhofer FEP, under the leadership of Annett Arnold, made all the preparations for the conference. The tenth anniversary of the ICCG was marked by the conference being given a completely new "corporate design" which was the brainchild of the Braunschweig designer Claudia Albrecht.

Almost 500 coating experts from about 30 countries participated in the conference which was held on 18th - 22nd June in the "wechselbad Theater" in the center of Dresden. Just over half the delegates came from Germany, with the USA (45 participants) and Japan (39 participants) also being strongly represented. Since its inception a feature of the conference has been the close dialog between research and application. The ICCG 2006 lived up to this with representatives of universities and other scientific organizations mingling with scientists, technical specialists and managers from industry and discussing current developments and future trends in the coating of glass and transparent plastics. In deciding on the key topics for the conference account was taken of the fact that the coating of polymers is becoming increasingly attractive due to their lower weight and other advantages (e.g. fracture resistance). The practical nature of the conference was also highlighted by an exhibition in which 38 companies presented their latest products and services. The number of conference delegates and the number of industrial exhibitors at the ICCG 2006 exceeded the attendances at all the previous ICCG conferences.

As is traditional, the conference program began on the Sunday afternoon with two parallel "short courses" at the Fraunhofer Institute Center. The first course was devoted to the vacuum coating of architectural glass, thin film technology for displays and chemical gas phase deposition at atmospheric pressure. The second course focused on sol-gel coating processes and the characterization of optical layers.

The conference lasted three and a half days and the technical-scientific program was divided into seven thematically distinct sessions. In total there were 130 presentations, with 53 being posters. The introductory session as usual covered current market developments. M. Yuki from Asahi Glass Corporation (Japan) outlined the current requirements on thin films for flat displays. J. U. Rühle from Sulfurcell Solartechnik (Berlin) reported on his company's experience with the industrial production of CIS solar cells, focusing on the economic aspects (manufacturing costs per Wp). A. Matthai presented examples of intelligent car glass from the viewpoint of AUDI and Volkswagen. Controllable transmission and self-cleaning were highlighted. W. Hedderich from Exatec Deutschland gave a talk about the current status of development work on transparent anti-scratch layers on polycarbonate. To close this session N. Kaiser from the Fraunhofer Institute for Applied Optics and Precision Engineering in Jena gave an overview of coating processes and applications of films for spectacles and precision optics.

The discussions about new coating processes were dominated by high-performance pulse magnetron sputtering, the treatment of large substrates with large ion sources and atmospheric pressure based coating processes. As at previous conferences a considerable part of the lecture program was devoted to applications of layers on glass and plastics in the architectural field, car industry and also in display manufacturer and photovoltaic technology. Noteworthy were the new approaches for marketing controllable sun protection by means of electrochrome layers.

The explosive development of the market for flat screens has pushed the issues of availability and the cost of indium into the limelight (indium tin oxide, a transparent layer having high conductivity, is a key component of all displays). Although a representative of the Indium Corporation of America surprised the auditorium by stating "The Indium Corporation of America is confident of the sustained indium metal supply", scientists from the USA and Japan are discussing the use of alternative materials.

Once again the three best poster exhibits were awarded money prizes. These prizes went to

6th International Conference on Coatings on Glass and Plastics in Dresden

N. Sakudo (Kanazawa Institute of Technology, Japan), T. Kilper (Forschungszentrum Jülich, Germany) and M. Posadowski (Wroclaw University of Technology, Poland).

The ICCG 2006 can also reflect on successful supporting events. On the evening of 20th June the Dresden mayor, Dirk Hilbert, welcomed guests on the roof of the World Trade Center, with the dry clear weather allowing a spectacular panoramic view.
The social highlight of the conference was without doubt the conference banquet in front of the Lingnerschloss on the bank of River Elbe. Some of the renovation work at the Lingnerschloss was carried out by VON ARDENNE Anlagentechnik, an internationally operating constructor of vacuum plants based in Dresden. The short but violent thunderstorm on the evening of the banquet did not dampen the good atmosphere. For many of our international guests the view of the Elbe valley at dusk was unforgettable.

The international buffet was also excellent. A particular highlight was the show given by the "physics technicians" who surprised the guests with a spectacular series of physical and chemical experiments. An imploding oil drum, modification of the human voice by inhaling heavy or light gases and a melody produced with a laser beam and a comb enthralled the guests. Several days later the two "edutainers" performed their tricks in front of several hundred visitors at the Day of Technology at the Fraunhofer Institute Center.

At the end of ICCG 2006 on the afternoon of 22nd June 2006 a number of selected companies opened their doors to the conference delegates. FHR Anlagenbau, Fremat, Southwall Europe and VON ARDENNE Anlagentechnik offered tours around their premises. The Fraunhofer FEP also presented its research facilities for high-rate coating processes.

All in all the sixth ICCG was a great success. The organizers would like to thank the delegates and in particular the exhibitors and sponsors without whose generous support the conference would not have been possible. Special thanks also go to the many helpers from the Fraunhofer FEP (in particular Annett Arnold, Stephanie Batel, Sabine Kempe, Yvonne Leidiger, Annett Nedjalkov and Janek Wieczoreck) and to VON ARDENNE Anlagentechnik.

Selected papers at the ICCG 2006 will be published in a special volume of the journal "Thin Solid Films". The preparations for the seventh ICCG are already underway. This will be held in the summer of 2008 in Eindhoven, the Netherlands, under the local organization of TNO. ■

The 2nd Fraunhofer Symposium and Opening of the Show Room in Sendai

The co-operation between Sendai-City / Tohoku-University in Japan and Fraunhofer Institutes in Micro-Nano technology field, especially in MEMS, is going on. This co-operation has been initiated by Dr. Suzuki of SurFtech Transnational Co., Ltd. and Dr. Granrath of Fraunhofer Japan and is now being promoted for some years. Sendai-City is a center of the northern part of Japan. Tohoku University (Prof. Esashi) in Sendai has gained a world wide reputation in R&D of MEMS during the last years. After the official co-operation agreement between the top management of Fraunhofer head office in Munich and the mayor of Sendai-City on 15th July, 2005, the 1st Fraunhofer Symposium was successfully organized in October 2005 aiming to get to know each other.
The delegates of Fraunhofer Institute for Reliability and Microintegration IZM, Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Fraunhofer Institute for Electron Beam and Plasma Technology FEP and Fraunhofer Japan were invited as main speakers.

The 2nd Fraunhofer Symposium was held on 7th November just after the International Forum on Micro-Nano Hetero System Integration on 6th November in this year. In this symposium, IZM (Mr. Baum), IOF (Dr. Bräuer), FEP (Dr. Suzuki instead of Prof. Schultheiß) and Fraunhofer Japan (Dr. Granrath) were invited again as main speakers. Dr. Suzuki gave a talk with the title of "Pulse magnetron sputtering for micro-nano technology" as one of the co-authors of the FEP, where he emphasized that the Fraunhofer FEP would be able to provide new tools for the production of MEMS and other optical and electronics applications. The square pulse magnetron sputtering of FEP attracted many audiences with its various features. In fact, soon after the presentation, the key company of Sendai called "MEMSCORE" and its customers requested an immediate co-operation for MEMS applications.

After the symposium, the Japanese style opening ceremony of the MEMS show room was held at MEMSCORE. The establishment of the show room was firstly proposed by Dr. Suzuki in the meeting of the Sendai delegates and Fraunhofer IST and FEP management in Berlin. In the show room, MEMS related products and samples with posters of Tohoku-University, MEMSCORE and Fraunhofer Institutes (IZM, IOF, FEP and Fraunhofer Japan) are displayed permanently. Due to this, the local industries do have the opportunity to get to know Fraunhofer technologies in MEMS related fields, which is believed to be a good marketing of the technologies of the FEP and other Fraunhofer Institutes for the industries which are located far from Tokyo.

Afterwards a company tour to MEMSCORE, which is a pilot production center of MEMS, and to Sendai-Finland welfare R&D co-ordination center, which is one of the application field of the MEMS, was organized. At the end of this event, the key persons of Sendai-City and Fraunhofer participants had a meeting for further co-operation. There, the organization of the 3rd Fraunhofer Symposium, up-dating effort of the show room, a liaison meeting for the local industries by Fraunhofer Japan and SurFtech, and a visit of local industries in Sendai to Fraunhofer Institutes were proposed and in principle accepted by the participants. It is believed that the co-operation between Japanese companies and Fraunhofer Institutes will be created and accelerated through these activities. ■

Events by FEP

Dresden – City of Science 2006 "A Day of Technology" and "Long Night of Science" at the Fraunhofer FEP

Dresden was "City of Science 2006" and set itself the goal of bringing the residents of Dresden and visitors closer to science in a clear and perceptible way. Under the motto "Where elements come together", which highlights the close link between the city of Dresden and science, Dresden was presented as a center of science and technology in more than 450 events held throughout the year. The events were organized by the city of Dresden in collaboration with a wide range of scientific institutes, cultural organizations and industrial companies. The FEP took part in these events. One event was the "Long night of science" which was held for the fourth time on 30th June 2006 under the auspices of the Federal Ministry for Education, Science, Research and Technology (BMBF).

The Fraunhofer Institute Center opened its doors to school pupils at 10 a.m. on this day for the "Day of Technology". All of the 11 Fraunhofer Institutes situated in Dresden were involved in giving the curious students an insight into tomorrow's world. A variety of presentations, exhibitions and experiments, plus a creative and sport street, made science and research tangible in an informal way. A total of 1800 school pupils of different ages participated.

Personnel of the Fraunhofer FEP presented the coFlex® 600 plant and explained how plastic films are coated and outlined everyday applications of the products. The MAXI plant was also presented and it was demonstrated how a vacuum process can be used for protecting metal sheets and strips from rust. The pupils were given a presentation of how surfaces can be modified by an electron beam using the REAMODE plant. Even the younger pupils were able to learn "Where elements come together". The microscope marquee gave the pupils a close-up view of plants, animals and technical devices, whilst in the experiment marquee interesting experiments were undertaken with liquid nitrogen.

Another event was the celebratory renaming of the bus stop in front of the Fraunhofer site, which now bears the name "Fraunhofer Institute Center". Following this the World Cup 2006 quarter-final between Germany and Argentina was shown on a large screen, and even the President of the Fraunhofer-Gesellschaft, Prof. Dr. Hans-Jörg Bullinger, showed his enthusiasm for this.

At 7 p.m. the "Long Night of Science" was officially opened by the mayor, Dirk Hilbert. A further 2100 visitors streamed into the Fraunhofer Institute Center in order to enjoy the unique mixture of science and entertainment. One of the main attractions was the physics technicians with their science show full of exciting experiments and physical trickery. The highly successful "Long Night of Science" ended at 1 a.m. in the morning. We look forward to next year again welcoming anybody interested in spending a few hours with us in the fascinating world of science and being given a peep of tomorrow's technology behind the normally closed doors of our institute. ■

Girls' Day 2006 at the FEP

Girls' Day is a nationwide event whereby girls aged 13 to 16 are given an introduction to professions underrepresented by females. The girls are given an impression of daily working life in workshops, laboratories and offices in a wide range of fields of work and have the opportunity to make useful contacts.

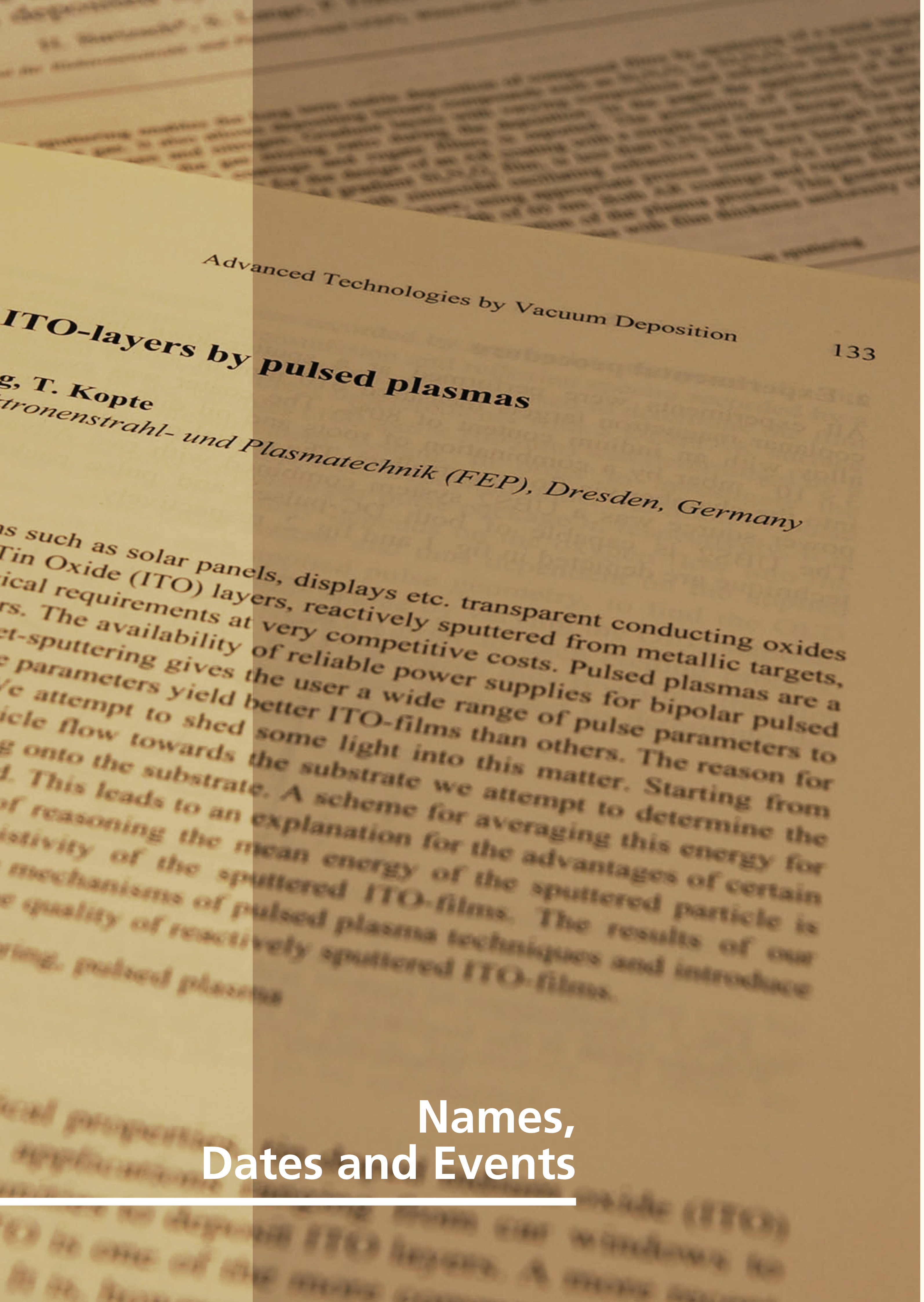
On 27 April 2006 the Fraunhofer FEP took part in this event for the second time. In conjunction with the Fraunhofer IKTS 45 girls aged between 13 and 16 were given an insight into work at a research institute. The girls were first of all given a tour around the Material Science / Analysis department. They were given the opportunity to see a scanning electron microscope and view things at great magnification which are not visible to the naked eye. Katharina Schäfer, a physics laboratory technician, explained the functions of many instruments to the girls and made them familiar with her work at the institute.

The girls were then shown around the plant halls. Dr. Heidrun Klostermann outlined how the coFlex® 600 and UNIVERSA plants worked. The girls were able to learn at first hand how a plasma process is used for coating flexible products such as films. Girls' Day 2006 enabled the FEP to help these girls make early choices about career direction. The FEP showed that work in science and technology can be very varied and highly interesting for girls. ■

"The Fascination of Technology - House of the Future" at Dresden Central Station

As part of the "City of Science 2006", an event entitled „The Fascination of Technology – House of the Future" was held at Dresden Central Station on 5th November 2006. The newly redeveloped Kuppelhalle was the unusual but appropriate setting for an interesting project in which a host of scientific organizations and industrial companies in Dresden presented their latest technologies to the public – so giving them an insight of daily life in tomorrow's world. The Fraunhofer FEP presented a demonstration device in order to demonstrate to both young and old the concept of self-cleaning windows. The technology behind this involves a photocatalytic titanium dioxide film applied via pulse magnetron sputtering which allows complete wetting of the glass surface and so promotes a cleaning effect.

More than 3000 visitors wandered about the "House of the Future" in order to discover what the science of the future holds for everywhere from the garden to the hobby room. Technical trickery, exciting exhibits and presentations were offered in a variety of ways. As part of "City of Science 2006", 150 children and youths were also awarded the junior doctorate title on this day. The open dialog between the attentive and interested public and the representatives of science and research organizations was a complete success for all involved. ■



Names, Dates and Events

Names, Dates and Events

Mitgliedschaft in Gremien

G. Bräuer
Mitglied des Koordinierungsausschusses des Arbeitskreises Plasmaoberflächentechnologie (AK Plasma)

G. Bräuer
Mitglied des Kuratoriums der Zeitschrift »Vakuum in Forschung und Praxis«

G. Bräuer
Mitglied des »International Organizing Committee« der »International Conference on Plasma Surface Engineering« (PSE)

G. Bräuer
Mitglied des »International Organizing Committee« der »International Conference on Coating on Glass and Plastics« (ICCG)

G. Bräuer
Mitglied des Vorstandes der Deutschen Gesellschaft für Galvano- und Oberflächentechnik e. V. (DGO)

G. Bräuer
Mitglied des Vorstandes neue Materialien Niedersachsen e. V. (NMN)

R. Bartel
Mitglied im Kompetenzzentrum Maschinenbau Chemnitz / Sachsen e. V.

N. Schiller
Mitarbeit im »Technical Advisory Committee« der »Annual Technical Conference der Society of Vacuum Coaters« (SVC)

G. Mattausch
Mitarbeit im VDE – ITG

N. Schiller
Mitarbeit im DFF

Ch. Metzner
Mitglied des Exekutivkomitees der ICMCTF als Session Chair der Session G5

F.-H. Rögner
Vertreter in der Fraunhofer Allianz Reinigungstechnik

H. Bartzsch
Europäische Forschungsgemeinschaft »Dünne Schichten« (EFDS), Silicon Saxony

G. Mattausch
Mitarbeit im Organizing Committee der EBEAM – International Conference on High-Power Electron Beam Technology

P. Frach
Mitarbeit im EFDS Fachausschuss »Oberflächen und Beschichtungen in der Bio- und Medizintechnik«

P. Frach
Mitarbeit im Photonic Net

P. Frach
Fraunhofer Allianz »Photokatalyse«

E. Schultheiß
Mitglied im DGO – Vorstand

E. Schultheiß
Mitglied in der Deutschen Vakuumgesellschaft

G. Bräuer
Mitglied des Aufsichtsrats der PVA TePla AG

G. Bräuer
Mitglied des Gesprächskreises »Plasmatechnik« für das BMBF

V. Kirchhoff
ELEWER - Der Elektronenstrahl als Werkzeug, Vorstandsvorsitzender des Vereins

N. Schiller
Mitglied des Fraunhofer Themenverbund »Polymere Oberflächen« (POLO)

G. Bräuer
Vorsitzender des »European Joint Committee on Plasma and Ion Surface Engineering (EJC/PISE)«

R. Bartel
Mitglied des Kuratoriums »Zenturm für angewandte Forschung und Technologie ZAFT e. V.«

Lectures

E. Schultheiß, P. Frach, H. Bartzsch, R. Bartel
Innovative process equipment and technologies for special coatings in microelectronics
Silicon Saxony,
Dresden, Germany
02. Februar 2006

E. Schultheiß
Fraunhofer FEP – kein langweiliger Ort für die Ausbildung…
University of Madras
Chennai, India,
03. Februar 2006

H. Morgner, Ch. Metzner, O. Zywitzki
Transparent, Abrasion Resistant Coatings onto Metal and Plastic Substrates
Seventh International Conference on Engineering and Design for Development PEDD7,
Kairo, Egypt
07. - 09. Februar 2006

M. Bedewy, H. Klostermann, T. Modes, O. Zywitzki
Reactive Pulse Magnetron Sputtering for the deposition of high quality AlN thin films
Seventh International Conference on Engineering and Design for Development PEDD7,
Kairo, Egypt
07. - 09. Februar 2006

H. Morgner, Ch. Metzner, B. Scheffel, F.-H. Rögner
PVD coating of metal strips and sheets – an overview
Seventh International Conference on Engineering and Design for Development PEDD7,
Kairo, Egypt
07. - 09. Februar 2006

E. Schultheiß
Plasmaaktivierte Hochratebedampfung für funktionelle Oberflächen
Festkolloquium Prof. Dimmigen,
IST Braunschweig, Germany
21. Februar 2006

E. Schultheiß
Entwicklungstendenzen in der Oberflächentechnik – Erfahrungen der Fraunhofer Institute FEP und IST
Meeting "Forschungsagenda",
Düsseldorf, Germany
22. Februar 2006

G. Bräuer
Schichten auf Glas – PVD-Basisprozesse und ihre reaktiven Varianten
OTTI-Profiforum,
Regensburg, Germany
22. Februar 2006

H. Morgner
Kratzfester durch plasmaaktivierte PVD-Hochratebeschichtung
MSTI / IIR Stuttgart,
Stuttgart, Germany
23. März 2006

G. Bräuer
Plasmen in der Beschichtungstechnik – Beispiele für aktuelle Entwicklungen
DPG-Frühjahrstagung Fachverband "Plasmaphysik",
Augsburg, Germany
29. März 2006

N. Schiller, V. Kirchhoff, M. Fahland
Vacuum coating of polymer films for display applications
FPD China 2006 SEMI Technology Seminars,
Shanghai, China
28. - 30. März 2006

H. Morgner, Ch. Metzner, O. Zywitzki
Abrasion resistant coatings onto metal, plastic and glass sheets
ICASE 8th International Conference on Advanced Surface Engineering,
Tokyo, Japan
25. - 26. April 2006

E. Schultheiß
Pulse-Magnetron Sputtering … a modern coating technology not only for optics and electronics
VDI Sitzung
Giessen, Germany
27. April 2006

J.-P. Heinß, Ch. Metzner
Experimental Results for the Substrate Cooling during High-Rate PVD
ICMCTF 2006,
San Diego, USA
01. - 05. Mai 2006

J.-P. Heinß, Ch. Metzner, B. Scheffel
Carbon Based Tribological Coatings - Deposited with Stationary Rates of 100 nm/s
ICMCTF 2006,
San Diego, USA
01. - 05. Mai 2006

E. Schultheiß
Nanokompositschichten und ihre Herstellung durch Plasmaverfahren
nano.tage
München, Germany
03. - 04. Mai 2006

E. Schultheiß
Als Physiker im Unternehmen der Fraunhofer-Gesellschaft - Ein Vergleich
Tagung "Physiker im Beruf",
Bad Honnef, Germany
05. - 07. Mai 2006

F.-H. Rögner
Aktuelle Trends in der industriellen Reinigungstechnik
Technologietreff des InnoRegio Freiberg e. V. ,
Freiberg, Germany
11. Mai 2006

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PVD Coating of Metal Strips and Large Metal Sheets
Meeting with Tung Tay,
Shanghai, China
25. Mai 2006

J.-P. Heinß, Ch. Metzner, B. Scheffel
Kohlenstoffbasierte tribologische Schichten, aufgedampft mit extrem hohen Raten
EFDS-Workshop "Kohlenstoffschichten - tribologische Eigenschaften und Verfahren zu ihrer Herstellung",
Dortmund, Germany
08. Juni 2006

T. Kopte
Layer stacks and applications of architectural glass coating
Tutorial of the 6th International Conference on Coatings on Glass and Plastics ICCG,
Dresden, Germany
18. - 22. Juni 2006

M. Fahland, A. Braem
Deposition of Reflection Layers on Metal and Polymer Substrates for the CMS Experiment at CERN
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Dresden, Germany
18. - 22. Juni 2006

E. Schultheiß, R. Schmittgens, B. Meyer
Large Area Deposition of Functional Plasma Polymers on Polymer Substrates
SPPC Prague,
Prag, Czech Republic
26. - 29. Juni 2006

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PVD Beschichtung metallischer Bänder und Platten
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Hohenlimburg, Germany
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G. Bräuer
Deposition of Transparent Conductive Oxides by High Power Pulsed Magnetron Sputtering (HPPMS)
Third Sheffield HIPIMS and ABS Days,
Sheffield, United Kingdom
12. Juli 2006

Ch. Metzner, F.-H. Rögner
Recent Developments in PVD Coating for Steel Strips
Invited lecture at the 18th annual conference on iron & steel technology at POSCO,
Pohang, Korea
24. - 25. August 2006

E. Schultheiß
PVD-Beschichtungstechnik für Optik und Elektronik: FEP Dresden als Systemlieferant
Kolloquium TU Ilmenau,
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30. August 2006

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Zr-Al-N nanocomposite coatings deposited by Pulse Magnetron Sputtering
E-MRS 2006 Fall Meeting,
Warschau, Poland
04. - 08. September 2006

P. Frach, D. Glöß, S. Klinkenberg, D. Kuang, S.M. Zakeeruddin, T.N. Murakami, P. Liska, M. Grätzel
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Garmisch-Partenkirchen, Deutschland
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High-rate electron beam deposition – the possibility of high-quality coating of large areas
Sur/Fin,
Milwaukee, USA
20. September 2006

O. Kobsch, U. Gohs, H. Michael
Modifizierung von Kunststoffen mittels Elektronen
Fachtagung für Elektronenstrahltechnik,
Universität Erlangen,
Erlangen, Germany
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Magdeburg, Germany
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VaQum Magdeburg,
Magdeburg, Germany
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E. Schultheiß
Gesputterte und reaktiv gedampfte TiO_2– Schichten - Vergleich der Eigenschaften
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27. September 2006

J. Weber, H. Bartzsch, P. Frach, J.-S. Liebig
Innovative stationary magnetron sputtering technology for optical coatings
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Berlin, Germany
01. Oktober 2006

R. Bartel
Der Elektronenstrahl als Werkzeug für die Mikrobearbeitung - vom Institut Manfred von Ardenne zum Fraunhofer-Institut für Elektronenstrahl- und Plasmatechnik Dresden
Vortrag TU Dresden,
Dresden, Germany
06. Oktober 2006

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Prozessidentifikation für InSitu-APC an Plasmabeschichtungsanlagen
Workshop "Test und Diagnose von Maschinen, Anlagen und ihrer Software",
Dresden, Germany
10. Oktober 2006

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Transparenter Kratzschutz durch plasmaaktivierte Hochratebeschichtung
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11. Oktober 2006

G. Mattausch, H. Morgner, Ch. Metzner, O. Zywitzki
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J. Fahlteich
Transparente Permeationbarrieren auf flexiblen Substraten
Institutsseminar,
Technische Universität Chemnitz,
Chemnitz, Germany
20. Oktober 2006

F.-H. Rögner
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15. November 2006

P. Frach, H. Bartzsch, D. Glöß, V. Kirchhoff
Nutzung des Pulsmodus als technologischer Parameter beim reaktiven Puls-Magnetron-Sputtern
Workshop "Plasma-, Ionen- und Elektronenquellen und ihre Stromversorgungen",
Dresden, Germany
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Plasmagestützte Verfahren zur Vorbehandlung metallischer Platten und Bänder
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Fakultät für Werkstoffwissenschaft und Werkstofftechnologie
20. Januar 2006

W.-M. Gnehr
Untersuchungen zum reaktiven Puls-Magnetron-Sputtern von ITO von metallischen Targets
Technische Universität Ilmenau Fakultät für Mathematik und Naturwissenschaften
20. März 2006

Th. Albrecht
Einsatzvorbereitung des Elektronenstrahl-schweißens in der Sensor-Industrie
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Fachbereich Maschinenbau/Verfahrenstechnik,
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M. Petschel
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B. Meyer
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Publications

S. Ohno, Y. Kawaguchi, A. Miyamura, Y. Sato, P.K. Song, M. Yoshikawa, P. Frach, Y. Shigesato
High rate deposition of tin-doped indium oxide films by reactive magnetron sputtering with unipolar pulsing and plasma emission feedback systems
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Volume 7, Issue 1, January 2006, Pages 56-61

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Proceedings im Tagungsband, Europäische Forschungsgesellschaft Dünne Schichten e. V. -EFDS-: Workshop Plasma-, Ionen- und Elektronenquellen und ihre Stromversorgungen 2006, Dresden : EFDS, 2006, S.1-11

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Science and Technology of Advanced Materials 7 (2006) 56-61

Technical Poster

P. Frach, D. Glöß, O. Zywitzki, M. Vergöhl, F. Neumann, K. Hund-Rinke, I. Trick
Decomposition ability and bioactivity of photocatalytic TiO_2 based layers prepared by reactive pulse magnetron sputtering
Workshop "Photokatalyse - Potenziale und Trends", Braunschweig, Germany
10. Mai 2006

H. Bartzsch, P. Frach, J. Weber
Innovations in stationary magnetron sputtering of optical coatings
Proceedings of the 6th International Conference on Coatings on Glass and Plastics ICCG, p. 295,
Dresden, Germany
18. - 22. Juni 2006

J.-P. Heinß, Ch. Metzner, B. Scheffel
Carbon Based Tribological Coatings by Using the High Rate Electron Beam Evaporation
PSE 2006,
Garmisch-Partenkirchen, Germany
10. - 15. September 2006

O. Zywitzki, T. Modes, E. Reinhold, Ch. Metzner, B. Scheffel, C. Steuer:
Characterization of titanium nitride layers deposited on steel strip by reactive plasma activated EB evaporation
Tenth International Conference on Plasma Surface Engineering, Garmisch-Partenkirchen, Poster session: Industrial Device Technology,
10. - 15. September 2006

E. Schultheiß, P. Frach, H. Bartzsch, R. Bartel
Innovative process equipment and technologies for special coatings in microelectronics – Innovative Prozessausrüstung und Technologien für Spezialschichtsysteme in der Mikroelektronik
Sendai Symposium Japan
21. Oktober 2006

Patents

Patent
EP 1 387 897 B1
Elektrodenanordnung für die magnetfeldgeführte plasmagestützte Abscheidung dünner Schichten im Vakuum
T. Winkler, D. Weiske, Ma. Junghähnel, K. Goedicke, Prof. V. Kirchhoff, J.-St. Liebig, Dr. T. Kopte

Patent
EP 1 397 525 B1
Einrichtung zur plasmaaktivierten Bedampfung großer Flächen
Dr. M. Neumann, St. Straach, M. Krug, Dr. N. Schiller

Patent
EP 1 462 538 B1
Verfahren zum reaktiven Magnetron-Sputtern
K. Goedicke, Dr. F. Fietzke, Dr. H. Klostermann, Dr. T. Wünsche

Erteilungsbeschluss
DE 102 34 859
Einrichtung und Verfahren zum Beschichten von Substraten
Dr. P. Frach, Dr. H. Bartzsch, K. Goedicke, T. Winkler, J.-St. Liebig, Prof. V. Kirchhoff

Erteilungsbeschluss
DE 102 44 438
Verbundkörper mit einer verschleißmindernden Oberflächenschicht, Verfahren zu seiner Herstellung sowie Verwendung des Verbundkörpers
Dr. H. Klostermann, Dr. F. Fietzke, Dr. O. Zywitzki, K. Goedicke

Erteilungsbeschluss
DE 10 2004 006 530
Verfahren und Vorrichtung zum Einbringen von Gasen bei Vakuumbeschichtungsprozessen
Dr. U. Krause, Dr. U. Hartung, Dr. T. Kopte, I. Krause

Directions

Directions

By car

- Autobahn A4 oder A13, exit Dresden-Altstadt
- Bundesstraße B6, Hamburger Straße to Stadtmitte
- continue along Wilsdruffer Straße, Stübelallee
- at the end of the "Großer Garten" turn right onto Karcherallee
- at the next traffic light, turn left onto Winterbergstraße

By railway and tram

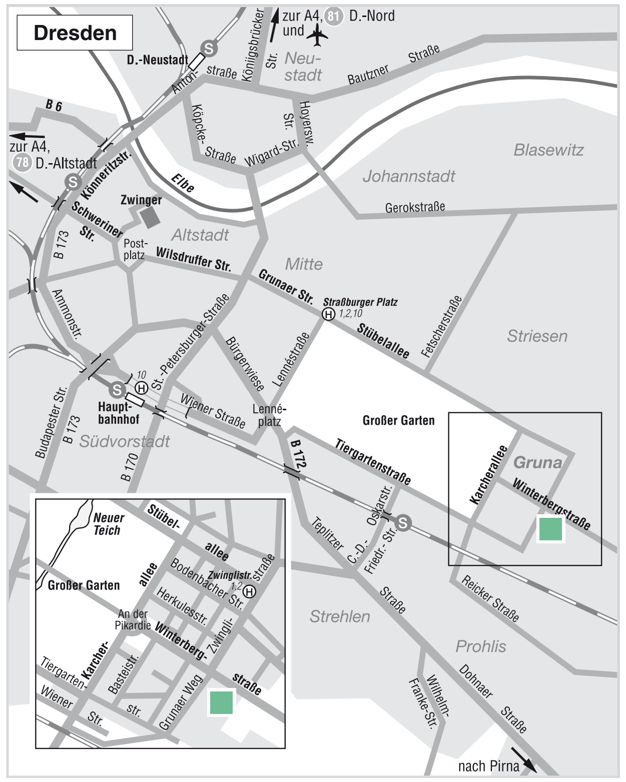
- from Dresden main railway station take line 10 to Straßburger Platz
- change to line 1 or 2 heading out from the city and exit at Zwinglistraße
- walk 10 minutes from there

By airplane

- from airport Dresden take a taxi to Winterbergstraße 28

GPS coordinates

- N 51 01.793
- E013 46.935



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vacuum coating

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Spotless arc **A**ctivated **D**eposition

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high rate deposition

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See you next year!