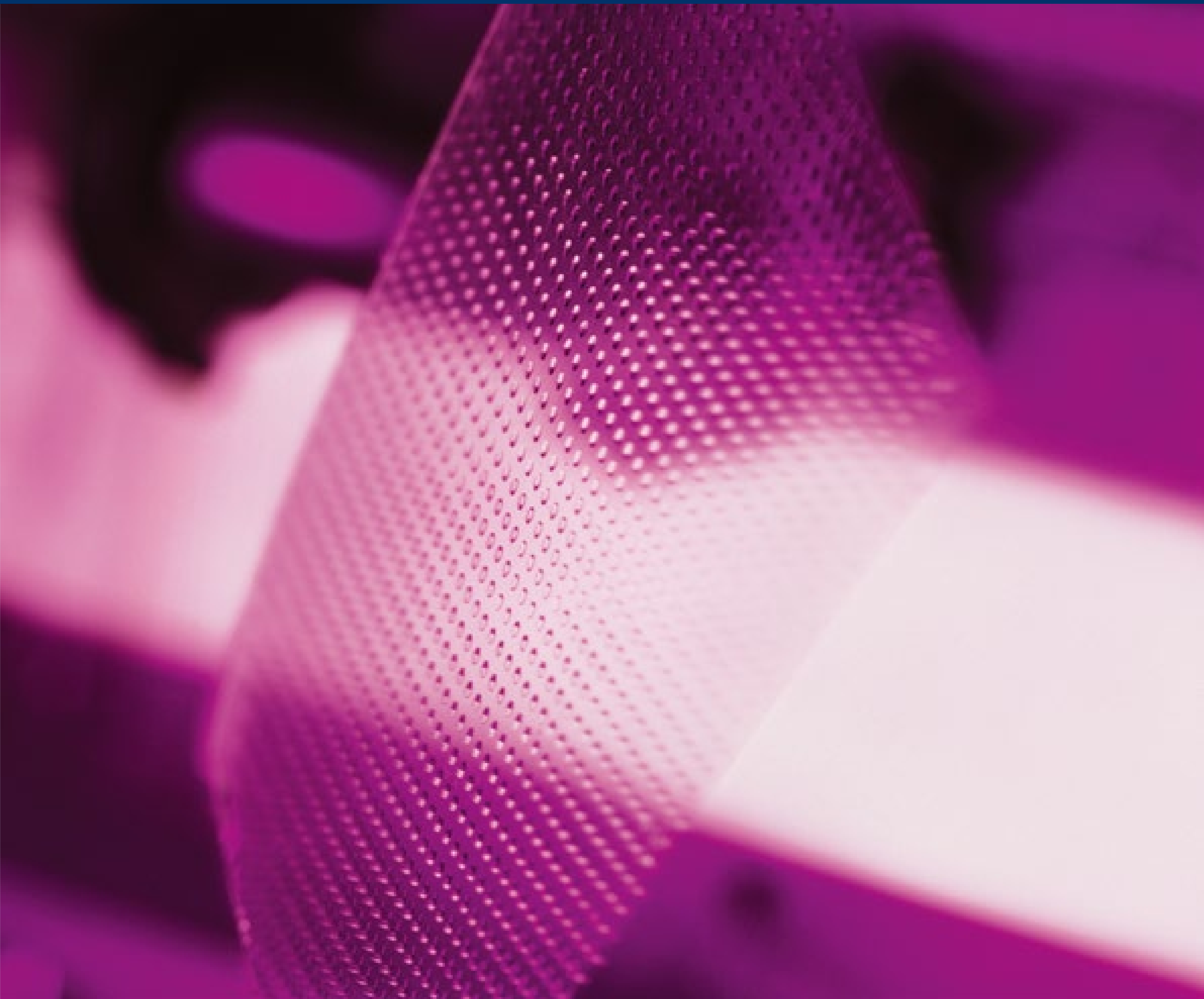
Fraunhofer IGB

FRAUNHOFER INSTITUTE FOR INTERFACIAL ENGINEERING AND BIOTECHNOLOGY IGB

PLASMA TECHNOLOGY
KEY TECHNOLOGY FOR THE PRODUCTION OF FUNCTIONAL SURFACES



PLASMA TECHNOLOGY

KEY TECHNOLOGY FOR THE PRODUCTION OF FUNCTIONAL SURFACES

Products with modified surfaces

In many technical products which we encounter in everyday life, thin layers are applied during the production and the surfaces are modified according to the requirements. Some technologies, such as painting or the galvanic deposition of metal, are familiar to everyone as they are relatively easy to carry out. Vacuum evaporation is also frequently used; coating with aluminum is the most widely applied method here. A well-known example is a bag of chips which has a thin aluminum layer on the inside to preserve the chips and keep them crisp.

Plasma-assisted processes are a further important field of technology. Plasma processes provide new and better solutions for many questions related to materials. In addition to plasma processes for etching, cleaning, activation, chemical functionalization and coating, to an increasing extent applications in the field of nanotechnology should also be mentioned.

The German Federal Ministry of Education and Research (BMBF) has identified seventeen future-oriented fields that deserve special attention as regards research policy. In fourteen of these fields, plasma technology will make a contribution as a key technology. This shows the great potential of this technology in an extremely wide range of applications.

Functional surfaces with plasma technology

Ever greater importance is being attached to the properties of surfaces in almost all industrial branches. For the surfaces of many materials, e.g. those of an industrial component or of a technically produced textile, different properties are frequently required than the material possesses in bulk. The material should be for example malleable, but its surface should be hard; textiles should be as resistant to stretching and dye-adsorptive as cotton, but at the same time water-repellent. Polymer materials are a further example of the use of surface technologies, because on the one hand they are chemically stable, outstandingly pliable and can be mass-produced inexpensively, on the other hand they often possess suboptimal properties as regards wettability, bondability, or scratch-resistance.

Surfaces can be modified with various objectives using plasma processes – at the same time preserving the bulk properties of the material:

- Surfaces are cleaned and activated, so that for example paints and adhesives adhere better to them.
- Surfaces are coated in order to provide new functions such as scratch-resistance, dirt-repelling properties or corrosion protection, or additional optical and electrical functions.
- Surfaces are given chemical functions that can react chemically with other substances.

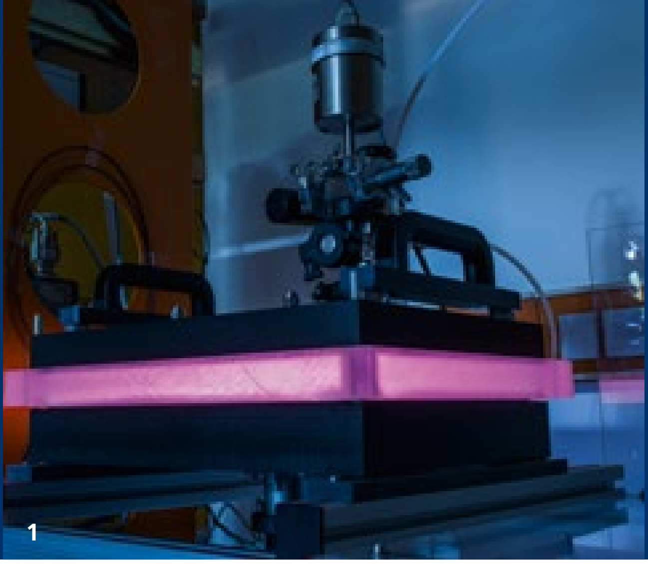
At the Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB, surfaces are first of all fully characterized with the aim of selectively modifying their properties and in a second step, they are fuctionalized using various modification and coating technologies.

Know-how through interdisciplinary cooperation

Thanks to many years of fruitful cooperation with cell- and micro-biologists at our institute, we have special know-how related to surface modifications in biology and medicine. The latest achievements in nanotechnology ranging from ultrathin layers to nano-biotechnology, where surfaces are characterized and tailored on the molecular or atomic level, are also characteristic for our work at the institute.

On the basis of various processes for interface modification, we at Fraunhofer IGB develop specific solutions for an extremely wide range of industrial tasks.

Deposition of barrier layers in a plastic container.



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What is an interface?

An interface is defined as the contact zone between two phases (materials). At such a phase boundary (interface), the properties of the material change abruptly. The phases themselves may be present in the same or in different aggregate states (solid/liquid/gaseous). Examples of phase boundaries with different aggregate states are surfaces of solids that are in contact with liquids or gases. However, there are also numerous examples of phase boundaries between two liquid phases (e.g. the phase boundary between unmixable liquids) and between two solid phases (e.g. the contact area between two different solids; grain boundaries within crystalline materials, or amorphous and crystalline areas). Phase boundaries or interfaces constitute the difference and thus are what is perceived. The atoms or molecules on the surface of the adjacent phases occupy a special energetic position on the periphery. In addition, they influence each other. Interfaces and surfaces are thus places where there is an imbalance of forces. The processes occurring there result in surface tension (interfacial energy), specific adsorption, material transition, or in the formation of an electrical field.

The term “surface” is also frequently used in this connection. However, strictly speaking this term only relates to one of the phases (for instance “glass surface”), whereas the term interface refers to the transitional area between the two phases.

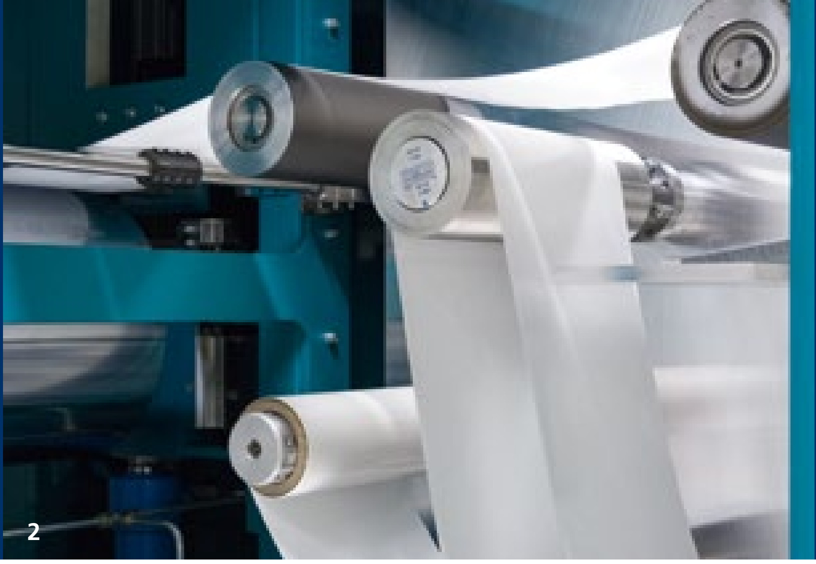
What is interface process technology for?
The aim of interface process technology is to adjust the interaction at the phase boundary. To do this, the surface of one or the other or both phases is altered with a specific purpose. In this way, tailored surfaces are created.

What is a plasma?
Plasmas are partially or completely ionized gases and vapors, which besides ions and electrons also contain chemical radicals and a large number of electronically excited particles. Far more than 99 percent of the universe known to us is in the plasma state. A plasma can be e.g. ignited and maintained by an electromagnetic field. Characteristic for each plasma is its luminescence which, depending on the type of gas and its pressure, shines violet, blue, green, yellow, orange, or reddish. The plasma luminescence is used in fluorescent tubes, e.g. as advertising signs. Argon tubes shine blue, neon tubes produce an orange-red light. However, vaporous liquids may also be used as the illuminating gas, for example in fluorescent lamps, which are generally filled with a mercury-argon mixture.

1 *Plasma reactor for artificial accelerated weathering.*

2 *Functionalization of web goods.*

3 *Plasma discharge in a holow sphere.*



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DEVELOPMENT OF EFFICIENT PLASMA PROCESSES

Energy-rich and reactive particles from the plasma gas phase bombard all materials which are exposed to them. Depending on the way the process is carried out, they may remove the uppermost surface atoms, create chemical functions on the surface, or deposit layers. Removal, functionalization and deposition occur simultaneously in every plasma treatment as elementary processes. Which of these processes determines the net outcome of the treatment – whether etching or coating is the final result – depends on various parameters of the process. At Fraunhofer IGB we ascertain for each task the optimal parameters for the particular modification of the surface properties aimed at.

Materials suitable for plasma treatment

In low-pressure plasmas that work at reduced pressure, all solids that are vacuum-compatible can be treated:

- Metals
- Most polymers
- Biomaterials and many other organic and inorganic substances.

The advantages of the low-pressure technology are the unparalleled layer homogeneity as well as the extremely low consumption of chemicals. With plasma processes, in particular low-pressure methods, even chemically inert materials such as Teflon® can be modified and made accessible to further processing (e.g. bonding). However, there are material related limits when materials are corroded too strongly in the plasma, whether chemically or by (UV) radiation as in the case of the plastic polyoxymethylene (POM).

Wide range of geometries

Shaped bodies (containers)

Most products are to be coated three-dimensionally, covering the entire surface. The plasma's ability to access the entire exposed surface plays a decisive role in the homogeneity of the treatment.

Flat materials (foils, textiles, membranes)

2D objects such as foils can be processed relatively easily. Woven textiles, fleeces and membranes can also be treated in plasmas. Here, depending on the application, we can selectively influence the in-depth effects of the plasma: Either that a functionality is only required on the surface, or that the bulk material is to possess the same characteristics. Fraunhofer IGB has a plant for the semi-continuous treatment of textiles.

Pipes and tubes

We also treat pipes and tubes in plasmas, the outside as well as the inside. Physically, one comes up against limits for inside treatment when the inside diameter (lumen) is substantially less then a millimeter. Here, the dependence on the process and material requires an appropriate amount of development work. At Fraunhofer IGB we have already treated materials with inside diameters of less than 200 µm.

Fibers and threads

We also treat fibers and threads as 1D solids. For this, we have continuous plants that work with low-pressure plasmas but where it is nevertheless possible, due to a sluice system, to guide the fibers "from air to air". As a result, the system can, for instance, be positioned directly in-line behind an existing fiber production plant (in-line operation).

Granulates and powders

To modify the surfaces of granulates and powders we use special setups combining particle placement in the plasma-zone and plasma-treatment. The smaller the particle size, the more difficult the process will be to control. This is due to generated charges at the particle surfaces. However, plasma treatment is also possible in this case by means of selective adaptations.

Process optimization for surfaces on demand

The Department of Interfacial Engineering and Materials Science of Fraunhofer IGB has many years of experience in the development and optimization of plasma processes for a very wide range of tasks. We control the processes within a plasma first of all via gas flow, pressure, excitation frequency and activity. The adjustment of these process parameters influences the density and energy of the charged particles, the density of chemical radicals and electronically excited particles as well as the radiation generated by the plasma – which all together determine the physical chemical effect of the plasma.

It has to be taken into account that the above-mentioned effects may vary spatially within a plasma, in particular in the vicinity of surfaces. In addition, there is a fundamental difficulty in the fact that the processes within the plasma cannot generally be controlled independently of one another, and the relative dependences frequently cannot be recognized easily. In order to gain insights into these and to optimize the plasma process, we use various methods for plasma diagnostics at Fraunhofer IGB.

Process and result control during the treatment and afterwards

The process parameters are continuously supervised and, whenever necessary, supporting plasma-diagnostic methods are employed. The surfaces exposed to the plasma are examined after the treatment using various methods, depending on the requirements. For this, we have comprehensive possibilities for surface analysis at our disposal which are described in separate brochures.

Our aim is therefore to optimize the process parameters and to establish controlled and reproducible processes.

1 *Treatment of bulk material.*

2 *Anti-icing coating of polymer foils by means of a continous roll-to-roll process.*

Advantages of plasma processes

Process-technical aspects

- Fine-cleaning, activation and coating in one process step
- 3D substrates can also be treated, even fibers and the insides of capillaries

Chemical aspects

- Chemical variety of the basic substances for plasma polymerization
- No auxiliary agents necessary for polymerization
- High degree of crosslinking
- Special functionalization, also of less active surfaces possible, e.g. hydroxyl, amino, aldehyde, carboxyl groups or grafting of large molecules

Layer properties

- Good adhesion to the substrate
- Homogeneous layer thickness and structure
- Surface and layer properties can be modified for a specific purpose
- Even thin layers remain pinhole-free

Economic and ecological aspects

- Low costs for initial materials and routine operation
- Low consumption of chemicals
- Solvent-free, dry process
- Closed process: stable and non-toxic precursors only become highly reactive in the plasma
- Less process waste

AREAS OF APPLICATION

New applications ranging over all branches of industry result from the use of nanotechnology. A leading role in this field is played, for example, by ultrathin coatings, turnable wettability, structured functionalized surfaces and so forth – some of these properties have already been mentioned in the applications listed before. Also methods that have already been established for some time such as thin-layer technology come under the newer general heading "nanotechnology". With the help of nanotechnology we were able to solve many interesting and challenging problems individually for our customers and project partners.

Plastics processing

One of the most fundamental points in plastics processing is the adjustment of wettability. This is also feasible with wet-chemical methods, but the corresponding auxiliary modification substances (e.g. chromic-sulfuric acid mixtures) can only be used when the safety precautions are taken and with comprehensive measures for disposal (see environmental aspects). Here, plasmas offer unrivaled advantages for almost all plastics, even for the modification of polymers on a fluoro(hydro)carbon basis (Teflon®). Besides wettability, bondability is a further very important point, and here, too, plasma technology represents an environment-friendly and inexpensive alternative to wet-chemical processes.

Water purification with plasmas

In the research area of water treatment the use of plasma processes as advanced oxidation processes (AOPs) is a very promising approach to the removal of trace organics. With plasmas, organics can be degraded simultaneously by radicals and ultraviolet light generated in the plasma. By this, residues of pharmaceuticals, cyanides, pesticides, etc. can be effectively oxidized. Furthermore, microorganisms can be inactivated. The plasma process can be configured to suit the drinking water treatment, process water treatment, the treatment of ballast water, etc.

Anti-icing coatings

Many technical systems can be affected in their function by snow and ice formation at their surfaces, e.g. in aviation and energy recovery (e.g. wind turbines), telecommunications and equipment and systems that use different external sensors. On rotor blades of wind turbines this can result in an unbalance. The aerodynamics will be affected, too. In sports and outdoor activities the adhesion of snow and ice can affect the functionality of the materials as well. Here, Fraunhofer IGB provides patented solutions based on combined surface and coating technology.

The metal-working industry

In the metal-processing industry, plasma technology is used for example for metal hardening. Also, oily or other residues can be cleaned off metals by means of plasmas (plasma fine-cleaning, see environmental aspects, page 12). At Fraunhofer IGB we concentrate above all on the methods that are related to metallic thin layers and composite layers. For this, we use plasma-based sputter techniques with which, depending on the purpose of the application, platinum, gold, titanium, silver can be deposited on surfaces. In addition, methods are used that substantially improve the adhesion of metals on the surfaces that are to be coated (e.g. plastics). Corrosion protection by means of plasma layers is a further important field of activity.

Packaging

In packaging technology barrier layers, against water vapor or oxygen, are playing an ever more important role. The packaging materials are frequently foils, bottles, canisters and so forth. Depending on the requirements, (aluminum) vacuum evaporation is often sufficient as barrier layer, or transparent monolayers or multi-layer systems are applied. Here, plasma technology provides highly crosslinked organic and inorganic layers which are stably bonded to the surface.

A focus of Fraunhofer IGB is on the development of barrier layers. In addition, we are also concerned with the development of surfaces with improved drain-off characteristics in order to reduce the amount of residue in the disposal. This is important for the foodstuffs, the cosmetics as well as for the chemical and pharmaceutical industries.

A further application is the deposition of decorative layers or the improvement of the layer adhesion of metallized decorative layers. Also safety labels that guarantee the authenticity of the packaging and thus are a protection against product piracy, can be produced by means of plasma technology. One example of this are fluorocarbon nanolayers on plastic foil underneath a colorative machine-readable metal layer.

The automotive sector

Many components in vehicles owe their good performance to plasma-technical modifications, beginning with protective layers for reflectors in headlights by way of bodywork and interior fittings to engine and transmission components.

The protective layer in reflectors ensures that the reflective aluminum coat used does not corrode and the headlights do not become “blind”. This layer consists of a very thin, transparent silicium-organic plasma polymer. In the bodywork area, some car manufacturers give plastic bumpers (e.g. on a polyolefine basis) a plasma treatment so that they can subsequently be painted more easily and more homogeneously. And then there is the wish to replace some of the glass with plastic (e.g. for reasons of weight). Because of the generally low scratch-resistance of polycarbonate, for instance, a scratch-resistant coating meets the requirements here.

The bonding of plastics is very important both outside and inside the vehicle. Furthermore mainly for decorative reasons, there is a preference for using metallized plastics. In both cases, preliminary plasma treatments result in substantially improved adhesion. Finally, the hardening of metals and alloys, and the application of hard, wear-resistant layers are topics that are nowadays dealt with by means of plasma technology.

In the automotive sector, we at Fraunhofer IGB concentrate mainly on questions that are concerned with the processing of plastics.

1 *Optimization of the wetting of ink feeding systems.*
2 *Rotorblades with anti-icing polymer foils.*
3 *Optimization of the friction behavior of ceramic bearings.*

MEDICAL TECHNOLOGY AND BIOTECHNOLOGY

Surfaces can be prepared in many different ways for medical technology or biotechnological applications. As shown in the table on the right, the interaction between surfaces and biological systems can be influenced and/or controlled. On the molecular and cellular level, surfaces can be prepared so as to enhance or reduce interaction. By applying plasma methods the surface of even chemically inert materials such as PTFE or PE can be activated and equipped with chemically reactive groups, including amino, carboxyl, hydroxyl or epoxy groups. By depositing plasma processes, various functional coatings are produced.

Biocompatibility

Biocompatible surfaces are essential for many applications in medicine and medical technology. At Fraunhofer IGB we have already made cannulae and stents biocompatible. Side effects can be avoided and an optimal functionality can be achieved.

Membranes for cleansing of blood

Plasmapheresis membranes of apheresis modules were modified at Fraunhofer IGB in such as way that endotoxin catchers could be bonded regio-selectively. (Endotoxins are lipopolysaccharides of bacterial origin, which can induce inflammations or sepsis.) With the plasma-treated membranes it is possible to free the blood 100 percent from these endotoxins.

Protein adsorption

In addition to this, materials can also be modified using plasma technology so that the protein adsorption on the surface is controlled. This comprises either an increase or a reduction of the adsorption, as well as selective addition of certain proteins and their orientation relative to the surface. These details are of great importance for cell adhesion, for example in tissue engineering.

Adhesion of cells and bacteria

Whether surfaces are colonized by bacteria or by mammalian cells, surface chemistry also depends on surface properties such as the topographical structure or elasticity. These properties can also be changed by plasma processes. In addition, we develop surfaces which minimize the colonization by bacteria. Here, the plasma technology serves to bond to the surface molecules which prevent the adhesion of bacteria. Also layers for releasing antimicrobial substances are being developed.

Plasma sterilization and absence of pyrogens

One focus at Fraunhofer IGB is establishing and extending processes for plasma sterilization and depyrogenization of thermolabile materials (see environmental aspects, page 12). Here, use is made of the fact that low-pressure plasmas have an inactivating effect not only on vegetative cells, but on spores and pyrogens (fever-causing residues of bacteria) as well. We were able to establish a plasma process in which even highly resistant endospores of various types of Bacillus become incapable of reproduction. At the same time, the specimens were freed of pyrogenic residues of microorganisms. We also use excimer plasmas to generate UV radiation between 172 nm and 308 nm for sterilizing surfaces and inactivating pyrogens.

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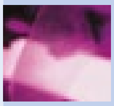
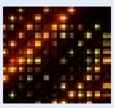
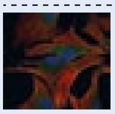
Cell culture technology

A main focus of work for the development of cell culture surfaces that encourage a selective proliferation is to be found in the control of molecular, mechanical, and topographical surface properties. In contrast to conventional approaches, we want to enable in this way the production of pure cultures of one type of cell that is required yet can only be isolated with difficulty. We also control the differentiation of cells via surface properties of the carrier material. Here we are following up various approaches to developing surfaces that encourage the growth of cells and which are suited to the selective cultivation of special cell types or that influence the differentiation of cells. This work is of great importance for the reproduction and separation of various cell types. Material surfaces are equipped with special chemistry by means of plasma technology, but also the mechanical and energetic surface properties are modulated here and optimized using these methods.

1 *Plasma treatment of contact lens.*
2 *Functionalization of surfaces of coronary stents.*
3 *Coating of dental implants by means of plasma processes.*

	**Interfaces of nanomaterials, membranes, films, textiles and medical devices and ...**	**Enhanced interaction**	**Decreased interaction**
	Proteins and other biological active molecules	Specific binding of bio-molecules for diagnostics, heterogeneous biocatalysis, specific scavengers	Decreased protein adsorption > minimized fouling
	Microbes	Immobilized microbes	Bacteriophobic, bacteriostatic, bacteriozidic surfaces, sterilization, desinfection
	Mammalian cells	Growing, proliferation and differentiation of (stem) cells, artificial organs and test-kits	Minimizing problems with temporary implants, minimized restenosis etc.

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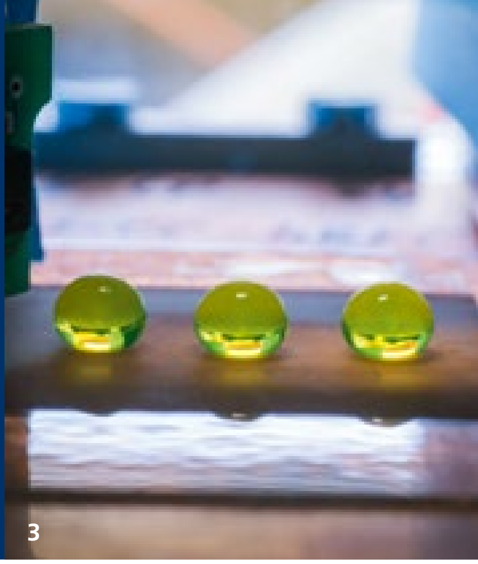

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OTHER AREAS OF APPLICATION

Pharmaceutical diagnostics

In this field the aim is to equip surfaces with biochemical functions in a defined density. Thus, we are dealing here with questions similar to those already dealt with under the heading Medical Technology and Biotechnology, like for example protein adhesion. In diagnostics, however, marker molecules can be used additionally. Fraunhofer IGB is participating in the development of various types of diagnostic biochips, in the production of which plasma technology is used among other techniques.

Energy technology

We are now carrying out development work in the field of photovoltaics where high-performance barrier layers against oxygen are required. In addition, we are working on making membranes available for energy technology that might be important for new types of fuel cells etc. However, not only applications for producing energy should be mentioned here. Energy saving by optimizing the surfaces of bearings, with a view to their tribologic properties, also makes a contribution in this field.

Electronics industry

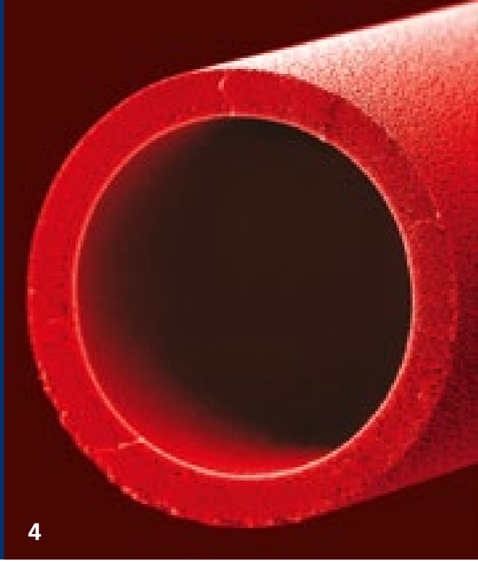
Plasma technology is the basic technology for producing structures in the semiconductor industry. With the help of nano-lithographic methods, structures smaller than 100 nm are now being used commercially. The most recent methods aim to achieve processor architectures with 32 nm (Nehalem-C, Intel).

The textile industry

Questions in the field of textile applications frequently concern hydrophilic or hydrophobic modifications as well as the dye-adsorbability of synthetic fiber and natural fiber-based materials. In the textile industry, both individual fibers and finished fabrics are to be treated.

In the case of individual fiber treatments, very high treatment speeds have to be achieved so that the processes can be integrated in the production plants. In the case of woven fabric treatments, the required treatment speeds are lower, however the demands on the plant technology are considerably higher. It is true that low-pressure processes have been used for many years for simpler problems such as the hydrophilization of polyester wovens. However, the replacing of vacuum by atmospheric pressure plasmas is also being used increasingly, as the simpler plants promise a reduction in costs. A great challenge especially in the treatment of wovens in atmospheric plasmas is the homogeneity of the treatment. In general, gaseous substances given off by the textiles may influence the process, in particular in the case of low-pressure methods.

However, in spite of these challenges, plasma technology offers great advantages, above all as regards the reduction of chemical waste. In wet-chemical processes, generally large amounts of special waste are produced, that has to be disposed of in the appropriate way. The plant costs for plasma plants that can replace wet-chemical steps therefore sometimes pay for themselves quickly.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Optics

Plasma processes can offer a large number of approaches for optical elements. Plasmas are sometimes used as sources of lighting that emit a certain spectrum depending on the composition of the plasma gas. Here, there are numerous developments aimed at replacing mercury in lighting. At Fraunhofer IGB we deal with optical thin-layer technology, to produce for example metal oxide or fluorocarbon layers with defined refraction index and antireflex layers. Scratch-resistant layers for lenses are also a frequent application. Also, we focus on medical-technological applications such as the surface modification of contact lenses. Fraunhofer IGB is as well focusing on the high-barrier layers that are required for the encapsulation of OLEDs (organic light-emitting diodes).

Membrane technology

Membrane technology is a main area of work at Fraunhofer IGB. By bundling these skills with plasma technology, new types of membranes are being developed. For medical applications, hollow-fiber membranes are listed under the heading medical technology and biotechnology. But there are quite different possibilities here. The standard is that separation membranes separate substances primarily according to the size of the particles contained in a mixture, but also by chemical interaction with the surface. Here, by means of plasma processes, chemical functional layers can be applied that macroscopically influence the diffusion and solubility properties of the membrane. On the one hand this takes place via the degree of crosslinking and on the other via the chemical function of the layer. This results in a large number of solutions for material separation.

Protecting the cultural heritage and restoring historical documents

Many cultural assets are exposed to harmful influences that may contribute to aging and decay, or are already damaged. Suitable methods for cleaning and conservation are decisive for the long-term conservation of the cultural heritage.

With plasmas, dirt and also harmful, for example, bacterial or fungal deposits can be carefully removed. The surface can then be permanently or temporarily provided with a protective layer. Even on sensitive organic materials such as old documents bacteria and fungi can be destroyed without damaging the surface, and the materials can also be protected from disintegration.

1 *Anti-icing and anti-soiling coatings on solar panels.*
2 *Fluorine-free, hydrophobic textile processing.*
3 *Adjustabe wetting by means of plasma processes.*
4 *Modification of hollow fibers for various applications (image © Gambro).*
5 *Sterilization of historical paper.*


1

ENVIRONMENTAL ASPECTS OF PLASMA TECHNOLOGY

Plasma technology offers a wide range of possible uses. It can replace numerous wet-chemical processes and dispense with solvents, which constitute a large part of the technological special waste. Especially low-pressure plasmas require a very low throughput of chemicals (six to seven orders in magnitude less than in comparison to wet chemistry).

Fine-cleaning of metals

Here we can mention as an example the otherwise solvent-intensive fine-cleaning of metals, for which water plasmas are occasionally to be preferred. When cleaning in smaller plants (40 L volume), one mol (18 g water) is sufficient for several cleaning cycles. This is possible because during the discharge, highly reactive particles are produced that attack dirt accordingly. The concentration of aggressive particles is in the meantime much lower than in liquid cleaning agents. This is not detrimental to the cleaning work as in low-pressure gas discharges, the mobility of the particles is higher than in liquids by several orders of magnitude. Also hardly any hazardous waste substances are produced. When the discharge is switched off, the active particles react, for example by recombining. Plasma cleaning in production plants can thus replace solvent-based cleaning methods.

Sterilization of thermolabile plastics

Thermostabile plastics are not suitable for conventional vapor sterilization. Conventional methods of low-temperature sterilization work with toxic or carcinogenic substances such as formaldehyde, ethylene oxide or peroxy acetic acid. With low-pressure plasmas a sterile surface can be obtained just by using a special mixture of oxygen and nitrogen at a power density of several mW/cm^2.

Chemical activation of plastics

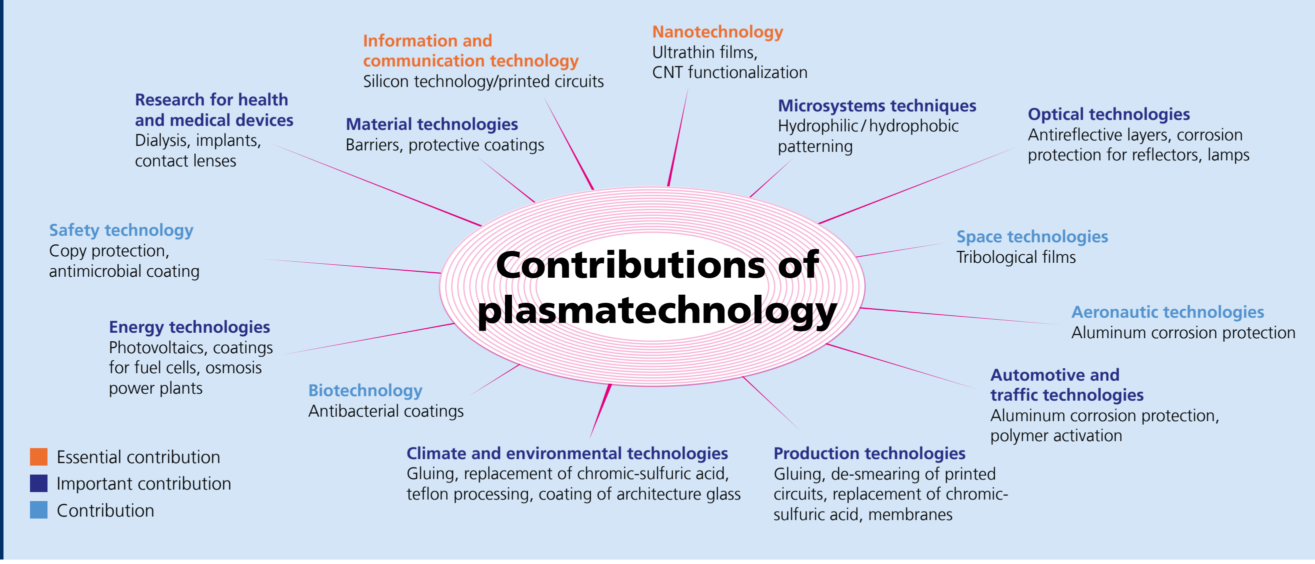
The chemical activation of plastics for the purpose of overcoating or bonding generally requires harsh conditions. Thus chromic-sulfuric acid for ABS-plastics and sodium naphthalenide in tetrahydrofuran for fluorocarbons are used as activators. However, these substances are flammable or toxic and must not be released! These treatment methods can be replaced by the use of various plasma processes.

Also the anti-felting of wool based on chloric compounds can be substituted by a more environmentally compatible plasma treatment. Moreover, plasma technology can also reduce environmental pollution in existing industrial processes by decomposing undesired (e.g. nasty smelling) or noxious waste gases by an appropriate plasma waste gas cleaning stage. This can also be applied to engine exhaust fumes.

Atmospheric or low-pressure plasma?

For many tasks, low-pressure plasma technology offers a better alternative to existing methods. It is especially suitable for surfaces that are sensitive to heat and chemicals, for coatings of the highest homogeneity and quality as well as for coatings that require environmentally hazardous substances, as here the use of chemicals is minimal compared with all other methods.

In atmospheric plasma processes, the costs for the vacuum technology are reduced or diminished. However, especially in coating processes, the throughput of chemicals is higher. Nevertheless, these plasmas are also superior to many of their wet-chemical counterparts as regards environmental technology. Where atmospheric plasmas can be used to a good purpose, as for example in the activation of fibers and fabrics before they are dyed, they can be integrated in existing plants.



COST-EFFICIENCY OF PLASMA PROCESSES

Frequently, supposedly high acquisition costs are put forward as a counter-argument against plasma technology. But even low-pressure processes are far less expensive than they may have been many decades ago. As a result of the versatile and increasing use of vacuum technology, not only in the semiconductor industry but also in many other branches of industry, the price for the creation of a vacuum has dropped substantially once again in past years. This applies both to the acquisition and provision of the plants and also – as a result of high technical quality and high efficiency – the running costs.

The financial costs of acquisition, installation and operation of a plasma plant are set against the high running costs of wet-chemical processes. Merely dispensing with processes involving various baths – besides the regular exchange and disposal of media there are also high costs for waste disposal – results in savings. In addition, wet-chemical methods can also cause high acquisition and maintenance costs – for often the chemical media have to be constantly monitored during use to check their quality. This requires the appropriate maintenance of the plant technology and sensors.

The outcome of all this is that plasma technology – in spite of substantially higher initial investment costs – on the basis of lower operational costs (e.g. disposal costs for baths) at same or better quality for example in the coating of contact lenses – has in the meantime replaced wet-chemical methods.

1 *Plasma treatment of polymer foils.*

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PLANT TECHNOLOGY

We have at our disposal a series of plants to carry out and further develop various plasma-chemical and -physical processes mainly in the low-pressure and subatmospheric pressure plasmas (0.01 to 300 mbar). If appropriate, we also work with plasma processes at atmospheric pressure. Besides commercially available plants (some of them modified), we have plants of our own design. For special specimen geometries and process requirements, we can quickly build suitable reactors and combine them with existing plant components (process gas, flow and pressure controls, vacuum components, high-frequency generators) to make laboratory or test facility plants.

Plasma excitation

- Frequency ranges: direct current, low frequency (kHz range), radio frequency (13.6 MHz), microwaves (2.45 GHz)
- Output: several W to 2 kW
- Continuous and pulsed excitation

Process gases

- Inert gases
- Reactive gases for surface modification (gases containing halogen, oxygen, hydrogen)
- Layer-forming agents (e.g. silane/siloxane, alkane/alkene, fluoroalkane/-alkene, amino and acrylic compounds)
- (Under)water plasmas

Plants

- Plants for the continuous treatment of woven fabrics and fibers
- Plant with plasma diagnostics
- Parallel-plate reactors
- Reactors for the treatment of tubes
- Plants for the plasma coating of the insides of bottles, canisters or other larger hollow receptacles
- (Reactive) magnetron sputtering
- Parylene® coating plant in conjunction with plasma processes

Plasma diagnostics: Insights into what happens physically and chemically

With plasma-diagnostics, a distinction has to be made between non-invasive and invasive methods. As invasive methods like probes can influence the plasma, we employ mainly non-invasive optical methods at Fraunhofer IGB:

- Microwave interferometry to determine the electron density
- Laser-induced fluorescence for the dissipated determination of particle densities in the plasma
- Optical emission spectroscopy to identify emitting species
- Surface temperature detection by measuring the fluorescence decay time of an excited crystal

The invasive methods we use are:

- Mass spectrometry to trace chemical reactions in the plasma
- Langmuir probes to measure the electron energy distribution, the density of the electrons and ions

OUR SERVICES

- Process development for the plasma modification of surfaces (powders, fibers, flat materials as well as shaped bodies)
- Layer development
  - Scratch protection, abrasion protection layers, layers with reduced friction
  - Anti-icing coatings to reduce ice adhesion and prevent ice formation on surfaces
  - Production of adhesive or dehesive agents
  - Corrosion protection layers
  - Barrier layers (e.g. impervious to oxygen and water vapor) and layers for packagings with improved drain-off
- Functionalization of surfaces
  - Biofunctionalization, chemical functionalization
- Development of plasma cleaning processes
- Development of water treatment using plasma-based AOP
- Development of plasma sterilization processes, UV and VUV lamps
- Surface and layer characterization
  - Geometry, morphology, roughness
  - Chemical composition, biological properties
  - Interfacial energy, adhesion
  - Color and haze
- Development of processes and plants
- Upscaling of the laboratory process
- Consultations, evaluation and feasibility studies to establish plasma methods as a technological alternative
- Patent and literature research on subjects relating to plasma technology

INTERNATIONAL NETWORK

Hon.-Prof. Dr. Christian Oehr

- Chairman of "Plasma Germany" (Working group Plasma surfaces technology), a committee representing an association of eight highly reputed scientific associations
- Editorial Board of the "Conference on Plasma Surface Engineering" PSE
- Editor-in-chief of Plasma Processes and Polymers (PPP)
- Board of Directors of the IUPAC Committee for Plasma Chemistry
- Board of Trustees "Vakuum in Forschung und Praxis" (VIP)
- Board of Directors of the Fraunhofer Polymer Surfaces Alliance (POLO®)

Fraunhofer Alliances

- Fraunhofer Additive Manufacturing Alliance
- Fraunhofer Photocatalysis Alliance
- Fraunhofer Polymer Surfaces Alliance (POLO®)
- Fraunhofer Technical Textiles Alliance
- Fraunhofer Cleaning Alliance

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Fraunhofer IGB brief profile

The Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB develops and optimizes processes and products in the fields of health, chemistry and process industry, as well as environment and energy. We combine the highest scientific standards with professional know-how in our competence areas – always with a view to economic efficiency and sustainability. Our strengths are offering complete solutions from the laboratory to the pilot scale. Customers also benefit from the cooperation between our five R&D departments in Stuttgart and the institute branches located in Leuna and Straubing. The constructive interplay of the various disciplines at our institute opens up new approaches in areas such as medical engineering, nanotechnology, industrial biotechnology, and environmental technology. Fraunhofer IGB is one of 69 institutes and independent research units of the Fraunhofer-Gesellschaft, Europe's leading organization for applied research.

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