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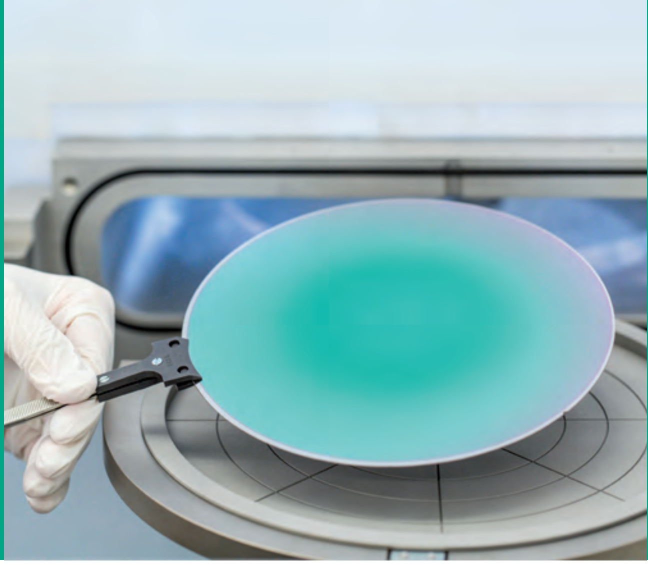
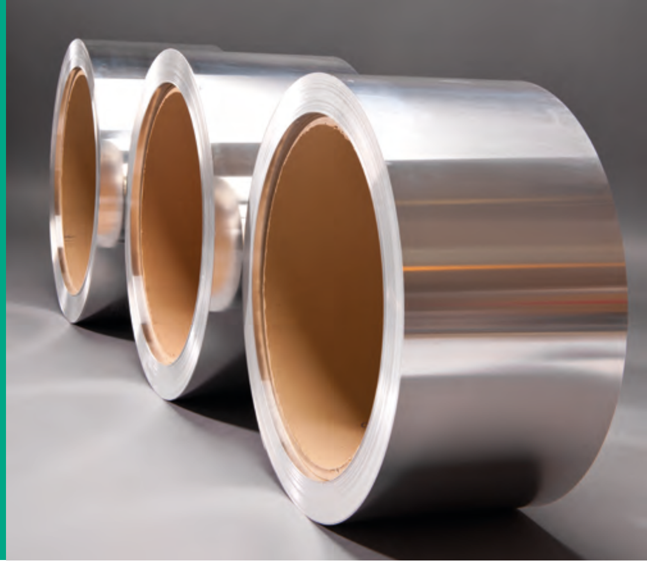
FEP

FRAUNHOFER INSTITUTE FOR ORGANIC ELECTRONICS, ELECTRON BEAM AND PLASMA TECHNOLOGY FEP

COATINGS

RESEARCH AND DEVELOPMENT:
APPLICATIONS – MATERIALS – SUBSTRATES – TECHNOLOGIES – SYSTEMS



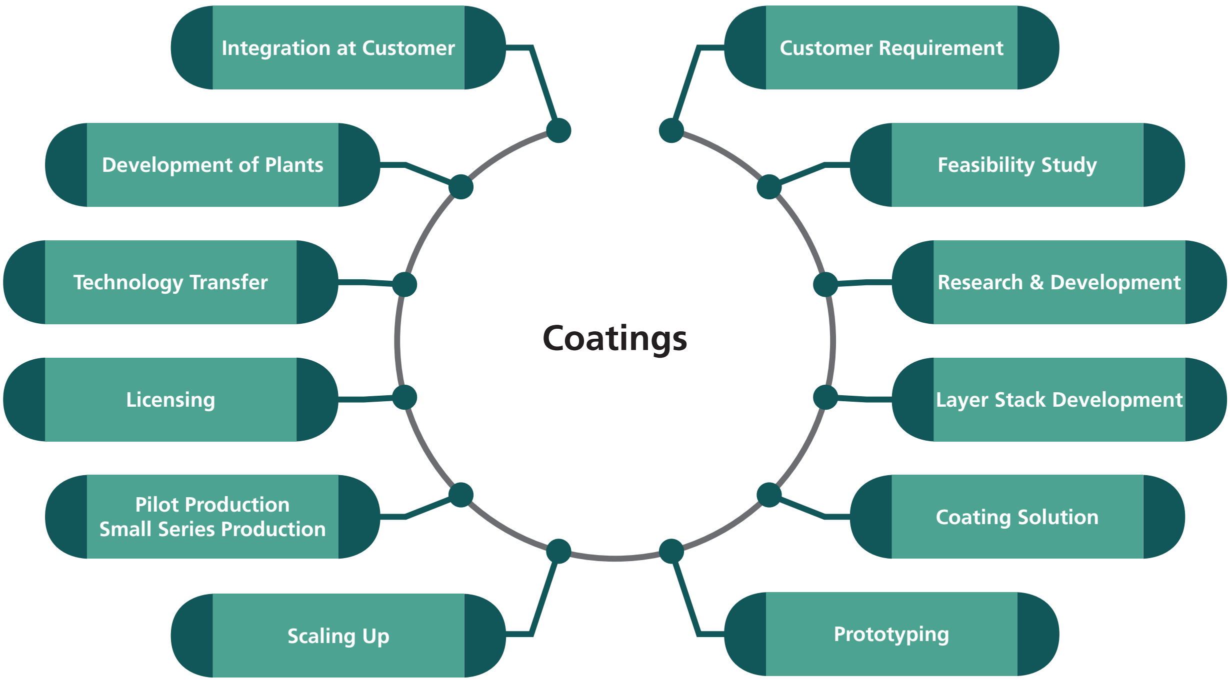


FOREWORD

Coatings of the highest precision are required for numerous applications in optics, electronics, sensor technology, energy and medical technology, mechanical engineering and automotive technology. Fraunhofer FEP develops processes and technologies to apply, for example, electrical, optical, acoustic or magnetically effective coatings and layer systems precisely and homogeneously to large surfaces using vacuum processes. In addition to the high environmental compatibility, the advantage of our processes is the almost inexhaustible range of depositable layer materials, which exceeds that of conventional surface finishing processes by far.

For our customers, we develop efficient technologies for the manufacture of innovative products whose functions are the combination of different layer properties is essential. Our services range from feasibility studies, layer stack development, small series coating and pilot production to the transfer of the technology into production based on high-performance components developed at Fraunhofer FEP. In addition, we are constantly expanding the range of substrate materials and coating technologies that we can use, thus advancing into new applications.

On the following pages you will find an excerpt of developed layers and coatings, presented from the perspective of the various subsequent fields of application that Fraunhofer FEP has realized in more than 25 years of research activity. These explanations are intended to give you an idea of the possibilities we can offer for you. Of course, all combinations and layer developments are adaptable with regard to materials, processes and customer- as well as application-specific conditions and parameters.



OPTICS AND DECORATION

Applications	Materials	Substrates	Technologies
Antireflex (AR)/Antireflex-Antistatic (ARAS)	Dielectrics: Al_2O_3, Cr_2O_5, MgO, Nb_2O_5, SiO_2, Si_3N_4, SnO_2, Ta_2O_5, TiO_2, ZnO, ZrO_2 Transparent conductive oxides (TCO): ITO, IZO, ZnO-based TCO, TiO_2-based TCO Metalle: Ag, Al, Cr, Cu, Mo, Sn, Ta, Ti, Zr, TiN	Glass, plastics, metal strips, metal sheets	Unipolar or bipolar magnetron sputtering, high-rate electron beam evaporation, plasma-activated electron beam evaporation, anodic arc evaporation
Electromagnetic shielding of elektronic devices			
Energy efficient construction (low-E, solar control)			
Mirror coatings (highly reflective mirrors, baroque mirror coatings, blue mirrors)			
Decorative layers			
Optical filters for laser optics, spectroscopy applications	SiO_2, Si_3N_4, Ta_2O_5, TiO_2, Al_2O_3, HfO_2, Nb_2O_5	Glass, plastics	Reactive pulse magnetron sputtering, high-rate PECVD
Anti-reflective coatings on eyeglass lenses			
Anti-counterfeiting labels, Decorative foils	SiO_2, TiO_2, Ag, Al	Polymer films, thin metal strips, flexible glass, membranes, textiles, paper, radiation-curable lacquers	Pulse magnetron sputtering, high-rate PECVD, high-rate electron beam evaporation, plasma and ion surface treatment, slot die coating, electron beam lacquer hardening

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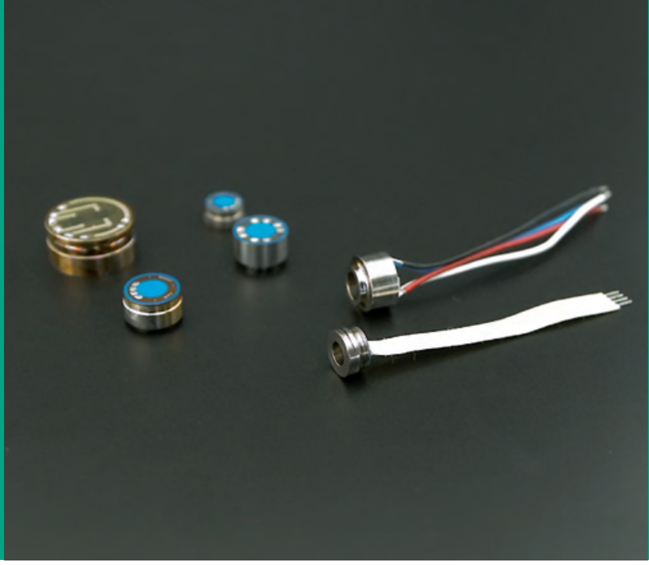

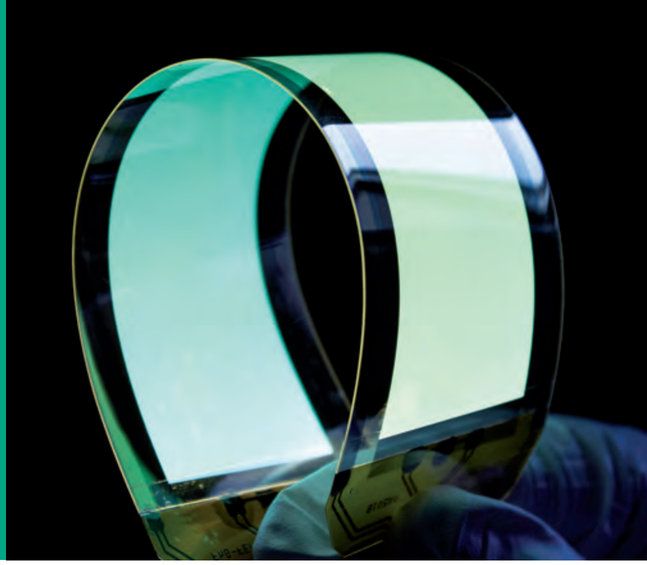

ELECTRONICS / SENSORS

Applications	Materials	Substrates	Technologies
High-barrier and functional webs for flexible and organic electronics	ZnSnO, TiO_2, Al_2O_3, organics, radiation-curing lacquers, ormocers	Polymer films, thin metal foils, flexible glass (thickness: 50 µm … 100/200 µm	Pulse magnetron sputtering, high-rate PECVD, high-rate evaporation, plasma and ion surface treatment, slot die coating, electron beam lacquer hardening, atomic layer deposition (ALD)
Solar cells			
Piezoelectric applications: ▪ Microsystems (MEMS), BAW, SAW ▪ Electroacoustic devices ▪ Ultrasonic microscopy ▪ Piezoactuators and sensors ▪ Microenergy harvesting systems	Crystalline AlN and AlScN layers with strong c-axis orientation	Silicon, steel, $LiNbO_3$, $LiTaO_3$, quartz	Reactive pulse magnetron sputtering, magnetron PECVD
Electrical insulation applications: ▪ Sensors (including device-integrated) ▪ Microelectronics ▪ Photovoltaics	Al_2O_3, SiO_2, Si_3N_4, $Al_XO_YN_Z$	Silicon, steel, copper, aluminum, glass, ceramics	Reactive pulse magnetron sputtering, magnetron PECVD
Heat dissipation components: ▪ Laser diodes ▪ Cooling for electronics ▫ thermoelectrics, peltier cooler ▪ Electronics development	AlN, $Al_XO_YN_Z$	Copper, aluminum	Reactive pulse magnetron sputtering, magnetron PECVD
Passivation, protective and barrier layers: ▪ Sensors ▪ Electronic components	Al_2O_3, SiO_2, Si_3N_4	Silicon, steel, plastics, glass	Reactive pulse magnetron sputtering, magnetron PECVD
Electronic and MEMS components	SiO_2, TaN, HfO_2	Silicon, ceramics, titanium, $LiNbO_3$, $LiTaO_3$, covar	Reactive pulse magnetron sputtering, magnetron PECVD
OLED, OPV and OTFT	Small molecules	Glass, polymer films, thin metal foils, flexible glass, wafers	tThermal evaporation (sheet-to-sheet or roll-to-roll)
Gas and humidity sensors	TiO_2, Fe, Ag, CuSn	Silicon, ceramics, glass	Reactive pulse magnetron sputtering, magnetron PECVD
Multilayer for electrical insulation layers with parylene	Parylene	Glass, polymer films, metal foil, silicon, thin glass, printed circuit boards	CVD at room temperature

CORROSION / SCRATCH PROTECTION

Applications	Materials	Substrates	Technologies
Corrosion protection	Ti, Al, Cr, Cu, Sn, ZnMg, Zn Thickness: 10 µm	Steel, stainless steel, precoated steel, copper, aluminum and their alloys	Vacuum based, e. g. physical vapor deposition (PVD)
	Parylene	Glass, polymer film, metal foil, silicon	CVD at room temperature
Wear protection, friction reduction, scratch protection, corrosion protection	a-C, ta-C (hydrogen-free amorphous carbon layers)	Steel, stainless steel, carbide, tools, sheet steel	Plasma assisted electron beam evaporation
Transparent scratch protection	SiO_x, Al_2O_3 Thickness: 1 … 10 µm radiation curing lacquers	Decorative films, decorative papers, high-pressure laminate (HPL) boards	Plasma assisted electron beam evaporation, electron beam varnish hardening

ENERGY CONVERSION, TRANSPORT, STORAGE AND BATTERY TECHNOLOGY

Applications	Materials	Substrates	Technologies
Current arresters for batteries and solar cells	Cu, Al	Polymer films, silicon wafer	Magnetron sputtering, electron beam evaporation, thermal evaporation
Thin-film photovoltaics	CdTe, CdS, Mo, CIGS, TCO	Glass, metal foil	Close spaced sublimation (CSS), plasma-enhanced close spaced sublimation (PECSS), magnetron sputtering, thermal evaporation, anodic arc evaporation
Crystalline photovoltaics	TCO, AlN, perovskite (for tandem cells), silicon thin film absorber	Silicon wafer, glass, steel	Magnetron sputtering, anodic arc evaporation, thermal evaporation, electron beam evaporation, electron beam crystallization
Anode materials for Li-based batteries	Silicon	Metal foil	Magnetron sputtering, high-rate electron beam evaporation
Solid electrolytes	LiPON	Metal	Thermal evaporation, electron beam evaporation

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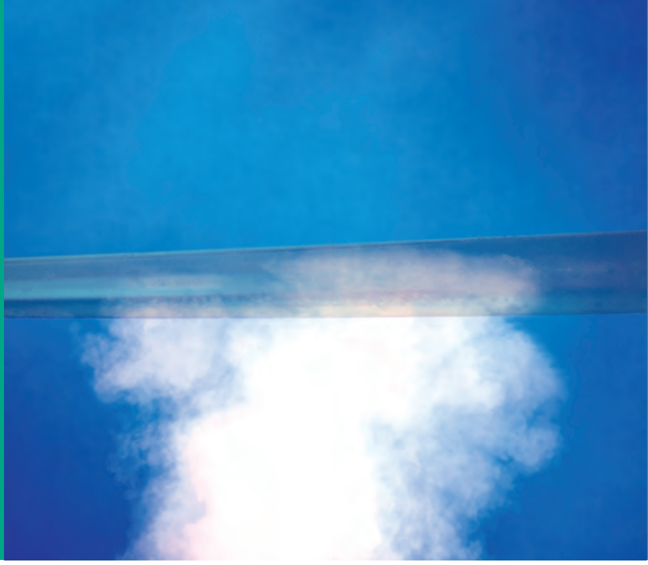


PERMEATION BARRIER LAYERS

Applications	Materials	Substrates	Technologies
Non-optical functional layers: ▪ Magnetic memories ▪ Scratch protection coatings on plastics ▪ Surface metallization ▪ Hard coatings	Dielectrics: Al_2O_3, Cr_2O_5, MgO, Nb_2O_5, SiO_2, Si_3N_4, SnO_2, Ta_2O_5, TiO_2, ZnO, ZrO_2 Transparent conductive oxides (TCO): ITO, IZO, ZnO-based TCO, TiO_2-based TCO Metals: Ag, Al, Cr, Cu, Mo, Sn, Ta, Ti, Zr	Glass, plastics	Unipolar or bipolar magnetron sputtering, anodic arc evaporation
Coating of flexible materials: ▪ Barrier films for packaging ▪ High-barrier for encapsulation of electronic components (e. g. solar cells, wearables, OLEDs, ...)	Al_2O_3, SiO_2, ZnSnO, SiN, Al, radiation-curing lacquers, ormocere	Polymer films	Pulse magnetron sputtering, high-rate PECVD (arc-PECVD), high-rate evaporation, electron beam lacquer hardening, slot die coating
▪ Ultra-high barrier coatings in combination with ALD or sputter coatings, ▪ Barrier films and substrates, ▪ Direct encapsulation (3D)	Parylene	Glass, polymer films, metal foil, silicon, thin glass, printed circuit boards	CVD at room temperature
Corrosion protection	Radiation-curing lacquers	Polymers, wood, metal sheet, papers, foils, glass, ceramics, metal	Electron beam lacquer hardening

 

PARTS, COMPONENTS, BULK MATERIALS

Applications, Function		Materials	Substrates	Technologies
Electrical function	Electrical conductivity, electromagnetic shielding	Metals, alloys, transparent conductive oxides	Plug contacts, chemical plant components, plastic housing	Electron beam evaporation, pulse magnetron sputtering, anodic arc evaporation
	Electrical isolation	Metal- and semiconductor oxides	Additively manufactured contact structures	Electron beam evaporation, pulse magnetron sputtering
Thermal function	Thermal conductivity	Metals	Heat storage granules	Thermal evaporation
	Thermal insulation	Stabilized ZrO_2	Turbine blades	Electron beam evaporation
Chemical barrier function	Corrosion protection	Aluminum-based, Cr, CrN	Rivet connectors, structural components in aviation	Thermal evaporation, Pulse magnetron sputtering
Mechanical protection function	Wear protection	Hard coatings	Tools, transmission small parts	Pulse magnetron sputtering
	Friction reduction	Metal alloys (AlSn base)	Plain bearings	Electron beam evaporation, pulse magnetron sputtering, high-rate PECVD
		Carbon based materials	Automotive and mechanical engineering components	
	Scratch protection	Metal nitrides	Commodities	Pulse magnetron sputtering
		Al_2O_3, Si_3N_4	Glass components	
Decorative function	Metallic look	Metals	Plastic components, sanitary pipes	Pulse magnetron sputtering
	Body colors	Metal nitrides	Fittings, spectacle frames	Pulse magnetron sputtering
	Interference colors	Metal oxides	Medical instruments	Pulse magnetron sputtering
Other functions	Specific optical function	Solar absorber layer systems	Solar collector tubes	Pulse magnetron sputtering
	Photoactivability, photocatalytic function	Titanium oxide	Dental implants	Pulse magnetron sputtering

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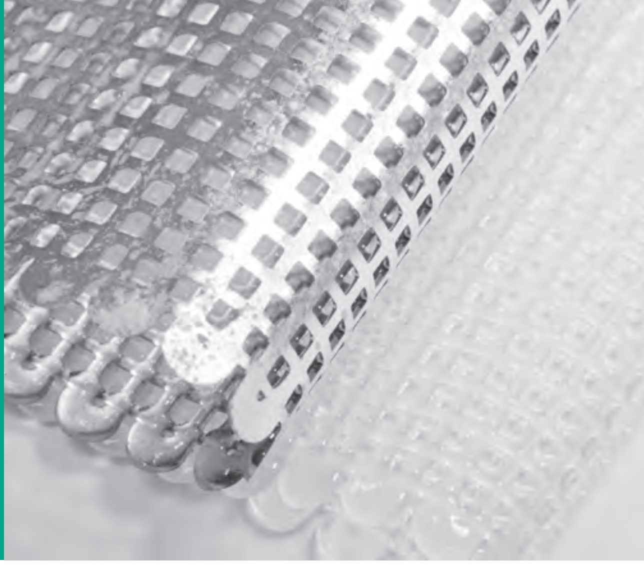

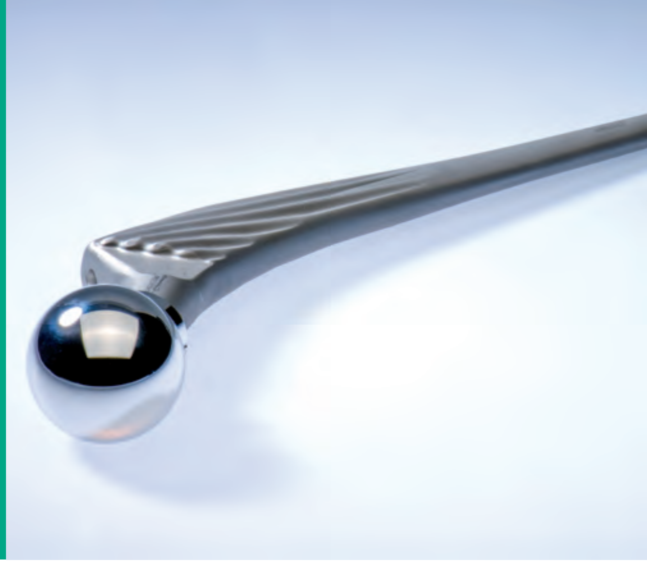

BIOMEDICAL APPLICATIONS

Applications	Materials	Substrates	Technologies
Biocompatibility for packaging and encapsulation	Parylene	Glass, thin glass, polymer film, metal foil, silicon	CVD at room temperature
Biocompatibility	ITO, ZnO:Al, AZO, TiO_2, Ag, Cu	Plastics, metals, thermolabile materials, organic materials and fabrics, ceramics, textiles, hydrogels, electronic components, polymer films, glass	Electron beam treatment, plasma treatment, vacuum-based processes for thin film deposition, roll-to-roll coating of flexible materials
Biofunctionality			
Antimicrobial coatings	Ag, Cu, Ag & Cu, TiO_2, doped TiO_2		
Electron beam based grafting			

OTHER FUNCTIONAL COATINGS

Applications	Materials	Substrates	Technologies
Hard coatings	TiN, TiC, WC, Al_2O_3, a-C(:H)(:Ti/W)	Metal sheets and strips	pulse magnetron sputtering, plasma-assisted electron beam evaporation
Electrically conductive	Al, Cu, Sn, Mo	Metal sheets and strips	pulse magnetron sputtering, plasma-assisted electron beam evaporation
Solderable and weldable	Cu, Sn, Si	Metal sheets and strips	pulse magnetron sputtering, plasma-assisted electron beam evaporation
Photocatalytic	TiO_2, TiO_XN_Y	Metal, glass, ceramics, plastics	Reactive pulse magnetron sputtering, plasma-assisted electron beam evaporation
Photo-induced superhydrophilic coating	TiO_2, TiO_XN_Y		Reactive pulse magnetron sputtering, plasma-assisted electron beam evaporation
Functional coatings for electro-acoustic components	SiO_2, TaN, F:SiO_2, AlN, AlScN	Silicon, ceramics, glass, metal, lithium niobate, lithium tantalate	Reactive pulse magnetron sputtering, magnetron PECVD
Substrate smoothing, laser stop layers	Parylene	Silicon	CVD at room temperature

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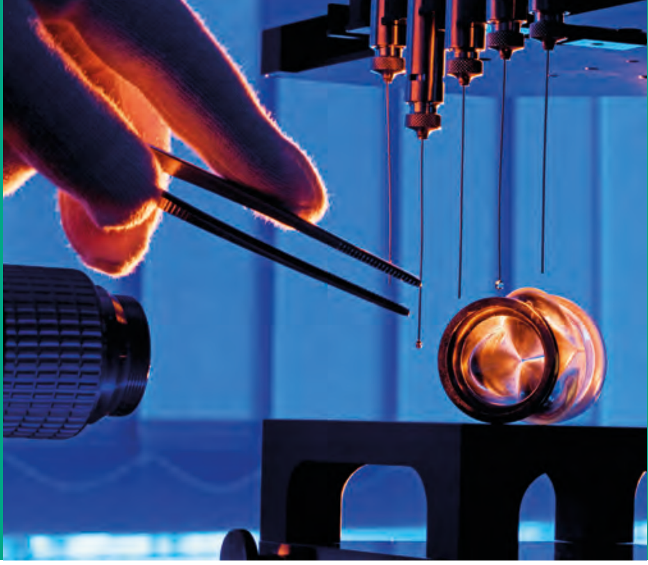


PRE-TREATMENT FOR COATINGS

In order to be able to coat substrates effectively, it is usually necessary and useful to pretreat the surfaces. Fraunhofer FEP has many years of expertise in various processes for **pre-treatment or surface functionalization**, which create the basis for high-quality coating and layer adhesion.

A coordinated **cleaning technology** is essential here so that the coating systems can be applied in an adhesive manner. Cleaning is therefore an important step in the value chain, which forms the basis for minimizing rejects, reducing costs and manufacturing high-quality products. A wide variety of impurities, in some cases down to atomic scales, as well as different requirements for the surfaces demand a range of different cleaning processes in order to achieve optimum results. At Fraunhofer FEP, this range includes, among other things, wet chemical fine or ultra-fine cleaning for metallic components or precision parts made of glass and plastic, plasma cleaning for components made of metal and plastic in a vacuum, local functional surface cleaning with electron beam in vacuum, and **sterilization, disinfection and inactivation** with accelerated electrons.

Furthermore, Fraunhofer FEP is researching and working on **surface functionalization**. Here, accelerated, low-energy electrons are used to specifically treat the relevant surfaces and generate, for example, antibacterial effects or self-cleaning surfaces. Electron beam treatment leads, for example, to an adjustment of the wettability of the surface (surface hydrophilicity). In this way, the interaction of the surface with the environment can be influenced in a targeted manner.

A special type of **surface treatment** is the **hardening** of suitable ferrous materials with the electron beam. In this process, a focused, high-frequency electron beam deflected over the workpiece surface leads to rapid, local heating of the material. The penetration depth can also be precisely controlled. The high heat conduction into the surrounding material then forces a high cooling rate without additional coolant (self-quenching), which leads to hardening of this surface layer in suitable materials. This allows local functional surfaces with excellent wear properties to be produced.

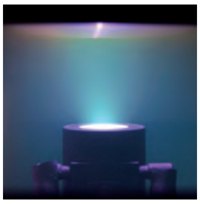
In addition, the electron beam can be used to smooth **rough surfaces** of many metallic components and thus prepare them for coating. The process is thus particularly suitable for the post-processing of additively manufactured parts. The active principle is that local energy input causes a momentary surface melting. The resulting melt immediately solidifies again, with the surface tension leading to a leveling of the height differences. With a suitable choice of parameters, **smoothing** takes place homogeneously over a wide area and, as far as possible, without material removal.

TECHNOLOGIES / PROCESSES

Electron beam technology

Thanks to our many years of expertise, we are able to utilize accelerated electrons in the energy range of 10 – 300 keV to apply thermal, chemical, and biological effects in a wide range of technological applications. Our strength is developing and delivering electron-beam technologies up through full industrial readiness. One unique selling proposition is the combination of technological and technical process developments and the development of special electron beam sources from a single source.

Plasma technology

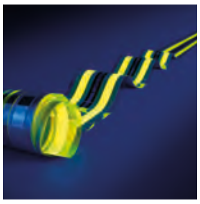


Plasma-assisted coating processes allow the production of customized coatings for many application areas. Our strength is to qualify these plasma-enhanced coating processes for industrial production and the coating of large areas.

The core competence includes the PVD processes, such as plasma-activated high-rate deposition and pulse magnetron sputtering as well as PECVD processes for plasma-activated chemical vapor deposition with various powerful plasma sources. A key unique selling point is the combination of very dense plasmas with extremely high deposition rates for the economical deposition of high quality coatings.

The combination of economic efficiency with precision in terms of process control and coating properties enables new applications. For these coating processes, we also develop the cleaning processes and plasma pre-treatments necessary to ensure coating adhesion.

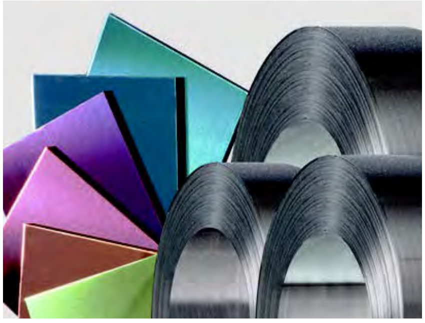
Organic electronics



Our core competencies in organic electronics include the development of technologies and processes for the manufacture of organic electronic components based on semiconducting hydrocarbon compounds. Pilot-production lines for sheet-to-sheet, wafer and roll-to-roll processing are available for this purpose. Our focus lies on process development for deposition and patterning of thin organic films as well as on encapsulation and system integration. The portfolio ranges from the creation of simple OLED layouts on glass or flexible substrates up to OLED-on-silicon (microdisplays) and device integration.

SUBSTRATES

Metallic sheets and strips



Bulk material and 3D components

Flexible films

Ultra-thin glass

Tools

Wafer

Other: cultural heritage (decoating)

Seeds (treatment)

Textiles (integration)

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