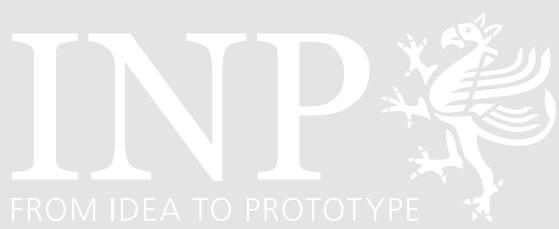


BIENNIAL REPORT 2022/2023

LEIBNIZ INSTITUTE FOR PLASMA SCIENCE AND TECHNOLOGY





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Ladies and gentlemen, dear friends and supporters of the Leibniz Institute for Plasma Science and Technology (INP),

It is with great pleasure that we present our annual report for 2022 and 2023, in which we can look back on many joyful events and successful developments. In these years, the INP has reached significant milestones, including the positive news at the beginning of 2022 that we have once again successfully mastered the Leibniz Association's evaluation procedure, which is unique in the German research landscape and can continue to be an integral part of the Leibniz Association. This successful start to the year 2022 marked the beginning of our anniversary year, in which we celebrated the 30th anniversary of the Leibniz Institute for Plasma Science and Technology.

A large number of positive results have been achieved in each research division in the years under review, excerpts of which can be found in the report. I would like to draw particular attention to the progress made by the three research alliances that are part of the "WIR!" funding programme of the Federal Ministry of Education and Research. With the joint projects "Campfire", "Physics for Food" and "BiogeniV", we as a research institute are actively shaping change in the region together with partners from industry and research. The same applies to the "Research Factory Hydrogen MV", which was launched at the end of 2023 with the support of the state of Mecklenburg-Western Pomerania (MV) and that will further accelerate the development of new technologies in the field of renewable energies and alternative energy sources in MV.

Another highlight of 2023 was the successful organisation of the "XXIII International Conference on Gas Discharges and their Applications", for which the INP was able to welcome researchers from all over the world to Greifswald for the third time since the INP was founded. Science thrives on exchange and collaboration across geographical and mental borders, and we are glad that we were able to experience an enriching conference with our guests despite the pandemic and geopolitically turbulent times.

In order to expand our leading position in the field of plasma technology in the international research landscape in the future, we have sharpened our profile over the past two years and are now addressing the social challenges of our time in the three research divisions: "Renewable Energies & Bioeconomy", "Plasma Chemistry & Process Technology" and "Health & Hygiene". Together with our partners and sponsors, we will continue the INP's success story at the sites in Greifswald, Rostock and Karlsruhe. Plasma technology as a cross-sectional technology remains on course for success, and the INP thanks its project partners and supporters for their trusting and constructive cooperation. Your trust and support along the way are invaluable. Special thanks are due to our employees for their valuable and dedicated work. Together, we will continue to contribute to making the future better for everyone through innovative research in the field of plasma technology in the years to come. We hope you enjoy reading this report.




Prof. Dr. Klaus-Dieter Weltmann
Scientific Director and Chairman of the Board



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INP passes evaluation procedure with excellent results

The INP has confirmed its position as a leading research institution in the field of low-temperature plasma physics and its applications in the Leibniz Association's evaluation process, which is globally unique. The international and independent jury assessed the institute's progress in new fields of application such as medicine and agriculture, the successful acquisition of third-party funding as well as effective management, successful company spin-offs and attractive working conditions extremely positively and recommended that the Senate of the Leibniz Association continues the financial support of the INP for further seven years. The evaluation confirms the excellent role of the INP in the development of solutions for social challenges, from renewable energies and environmentally friendly agricultural technologies to new medical processes.

INP WIR projects receive millions more in funding

As part of the BMBF's "WIR! - Change through innovation in the region" programme, innovative alliances in structurally weak regions are funded, in order to initiate and support regional structural change by means of cooperative research and development. In 2022, two of the three collaborative projects in this framework programme in which the INP is involved or leading, were positively evaluated and further funding was approved.

PHYSICS FOR FOOD uses physical innovations to promote more environmentally friendly agriculture. With additionally six million euros, the project aims to reduce the use of chemicals in agriculture and make plants more resistant to climatic challenges.

CAMPFIRE focuses on pioneering green ammonia technologies for a carbon-neutral energy future. The alliance will receive further six million euros in funding as part of the "WIR!" programme. Further federal funding of 31 million euros in total will flow over the next few years within the framework of the TransHyDE flagship project to establish Mecklenburg-Vorpommern as a core region for ammonia-based energy solutions and strengthen energy supply security.



EU funding for international doctoral network "PlasmACT"

Doctoral students from all over Europe aim to research the use of cold atmospheric pressure plasma to treat actinic keratosis, a precursor of skin cancer, during their doctoral phase. The EU approved funding of 2.15 million euros for this project "PlasmAct" in 2023 as part of the Marie Skłodowska-Curie Actions programme. The funding supports the mobility and career development of researchers across countries and sectors and is highly competitive. Only 15 per cent of applications were funded in 2023. Under the leadership of the INP, renowned European partners, such as the French Centre National de la Recherche Scientifique (CNRS), the Dutch Eindhoven University of Technology, Rostock University Medical Centre and the Belgian University of Antwerp, have joined forces for the project. In addition, 10 European companies support the students' training in order to prepare them as well as possible for careers in applied research.

Success in the Leibniz Excellence Competition

Together with the Leibniz Institute for Agricultural Engineering and Bioeconomy and the University of Rostock, the INP has successfully raised around one million euros for a research project in the "Leibniz Co-operative Excellence" competition in 2023. The aim of the joint project is to optimise central biomass processing processes - in particular to increase biogas production, phosphorus recovery and nitrogen enrichment in fermentation residues as an alternative fertiliser. In an era of raw material shortages and climatic challenges, this interdisciplinary project represents an innovative approach to the more efficient processing of agricultural biomass by use of physical plasma and ultrasound. This will make a significant contribution to a sustainable circular economy in the bioeconomy.

INP researcher receives Rudolf Seeliger Prize

Prof Dr Jürgen Röpcke was awarded the Rudolf Seeliger Prize of the German Society for Plasma Technology for his life's work. His work on laser absorption spectroscopy has made a decisive contribution to the understanding of reactive plasmas and opened up new possibilities for the control of plasma technology processes. Prof. Röpcke, who has been active in plasma research since 1982, has made a significant contribution to the development of plasma diagnostics and the application of modern laser technologies in industry.



„XXIII. International Conference on Gas Discharges and their Applications“ in Greifswald

The „XXIII. International Conference on Gas Discharges and their Applications“ (GD2023) took place in Greifswald in September 2023 in perfect weather with the participation of around 130 scientists and industry representatives from 21 countries. Organised by the INP, the Max Planck Institute for Plasma Physics and the University of Greifswald, the conference served as a platform for exchanging information on the latest developments in plasma research, including basic research and applications in energy, environmental research and technical diagnostics. GD2023 convincingly demonstrated how diverse and innovative plasma research is and the potential it offers for solving societal challenges. This is the third time that INP was chosen to host this prestigious conference.

INP receives “HR Excellence in Research Award” and “TOTAL E-QUALITY Award”

In 2023, the INP received the “HR Excellence in Research Award” for the second time. It is an EU seal of quality that recognises the commitment to optimal working conditions for researchers. This award, which 700 research institutions in Europe and 25 in Germany have received so far, proves that the INP successfully implements the European Charter for Researchers and the Code of Conduct for the Recruitment of Researchers. The INP received the “TOTAL E-QUALITY” award for equal opportunities for the fourth time in a row. This recognition confirms the INP's commitment to a gender-friendly and diversity-friendly organisational culture.

Appointment of new professorship for Translational Plasma Research

Dr Sander Bekeschus, researcher at the INP, was appointed W1 Professor for Translational Plasma Research at Rostock University Medical Centre. This appointment strengthens the cooperation between the INP and the Dermatological University Clinic in Rostock, particularly in the field of plasma medicine. Prof. Bekeschus, who has headed the “Plasma Redox Effects” research group since 2016, will continue to deepen his research into cold atmospheric pressure plasma in medicine. The focus is on wound healing and potential applications in cancer therapy.

Expansion of the Research Programme "Agriculture, Bioeconomy & Environment"

In order to strengthen the Research Programme "Agriculture, Bioeconomy & Environment", investments in the millions will be made by the federal and state governments over the next years in the form of special funding. The additional funding will be used to finance the establishment of specialised laboratories and infrastructure in the newly founded Centre for Life Science and Plasma Technology (Z4) in Greifswald. In addition, three new professorships are planned in the fields of "Biomass", "Agriculture" and "Food Processing". The professorships will be filled in co-operation with the University of Applied Sciences Neubrandenburg, the University of Greifswald and the University of Rostock. The professorships will be supplemented by further positions in the scientific staff, in order to further accelerate the dynamics and progress in this field of research.

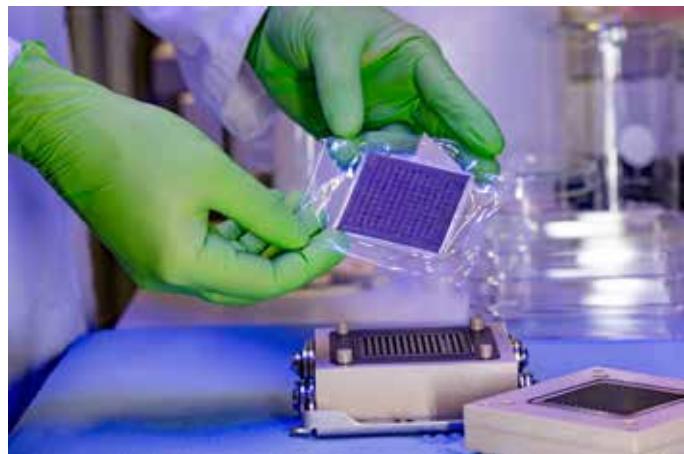
Better tree seeds by the use of plasma

The aim of the INP, phenolytics GmbH as well as the Scottish companies Elsoms Trees and Elsoms Seeds is to improve the quality of tree seeds through plasma treatment. The project partners intend to research innovative approaches to overcome the deep dormancy of tree seeds, which delays their germination until spring and makes previous propagation methods in tree nurseries more difficult. Plasma treatment will be used to increase the germination rate and speed and to improve the storability and health of native deciduous tree seeds in the United Kingdom (UK). The project is funded by the Tree Production Innovation Fund (TPIF) in the UK. The project promises significant progress for the forestry trade by more efficient seed propagation and could also contribute to the microbial decontamination of tree seeds.



"Research Factory Hydrogen MV" starts

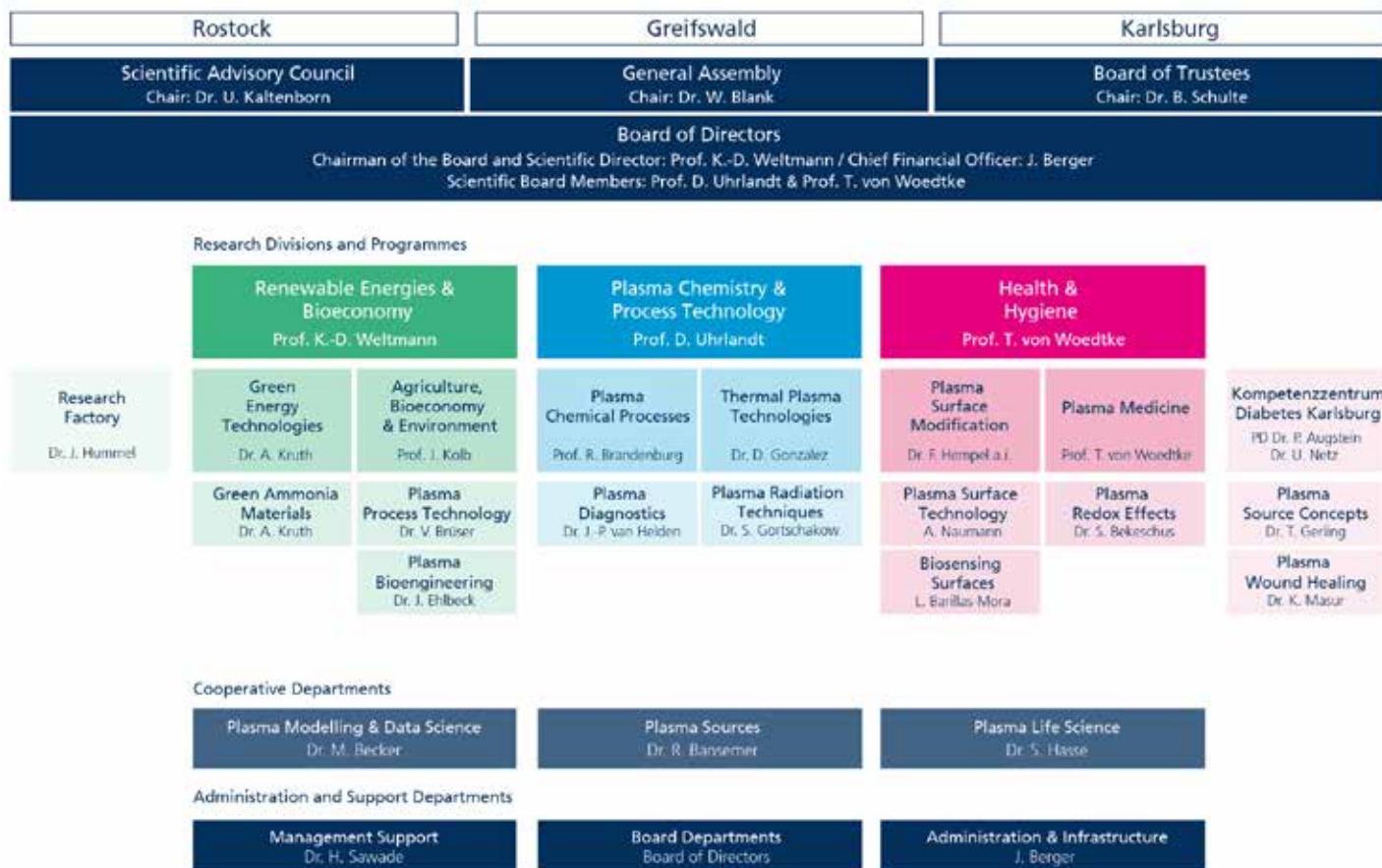
As part of the "Research Factory Hydrogen MV", the INP intensifies its research activities in hydrogen production using plasmalysis and driving forward the development of sustainable technologies until they are ready for the market. Plasmalysis is an energy-saving alternative to conventional electrolysis. It produces not only hydrogen but also valuable carbon for industrial applications. The INP is starting to set up a laboratory model for the production of hydrogen and carbon using plasma technology as well as an application centre in Greifswald. The Research Factory Hydrogen MV is a central project within the framework of the Maritime Future Concept in cooperation with the Fraunhofer Institute for Large Structures in Production Technology (IGP) and the Leibniz Institute for Catalysis (LIKAT) Rostock.



New INP spin-off in preparation

Scientists at the INP have developed an innovative solution for the resource-saving production of hydrogen that saves up to 90 per cent of the precious metals iridium and platinum used in electrolyzers. The INP researchers' innovation is based on a new type of membrane electrode assembly (MEA) for electrolyzers, produced using a combination of plasma technology and electrochemistry. This technology offers a decisive competitive advantage in view of the increasing demand for electrolyzers for climate-neutral energy generation. The German Federal Ministry for Economic Affairs and Climate Protection has recognised the potential of this innovation and is supporting its commercialisation with an "EXIST research transfer" grant of 1.2 million euros. The team plans to use this budget to finance the construction of a small-scale industrial plant in order to drive forward the establishment of their company. This will be the sixth time that the INP will have a successful transfer of research achievements to industry in the form of a spin-off.

ORGANISATIONAL CHART





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RESEARCH DIVISION

RENEWABLE ENERGIES & BIOECONOMY

Overview

The research division Renewable Energy & Bioeconomy focuses on plasma-based environmental technologies and innovations for the energy industry. Our technologies enable more environmentally friendly agriculture and improve plant health. We develop bioeconomic potential through new technologies for biogenic residues. Our decontamination processes purify liquids, gases and surfaces. We sterilize food on an industrial scale and remove pharmaceutical residues from wastewater. Our plasma-based synthesis processes are used to generate, store and reconvert renewable energies and to recycle CO₂. We develop materials and processes for hydrogen, photovoltaic, battery and power-to-X technologies. With new materials and combinations, plasma thin-film technology, surface modification and nanostructures, we provide solutions for the use of green ammonia materials in the energy supply. Plasma technology offers extensive opportunities for the development and cost-effective production of innovative materials.

Research Programmes of the Division:

Green Energy Technologies

Research Programme Agriculture,
Bioeconomy & Environment

Branch Office Research Factory

Overview

The climate change is one of the greatest challenges of this century. Industry and mobility are facing huge upheavals. The European Green Deal sets out the roadmap for a climate-neutral Europe and the Parliament has set targets for climate neutrality by 2050. Materials and technologies play a key role in this. New material architectures have to be developed on the nanoscale that realise high performance and long-term stability in the application, are sustainable and available, and are produced using processes suitable for industrial use.

The objectives of the GET research programme are based on the European Materials Roadmap "Enabling Low Carbon Energy Technologies" and the research and innovation activities for key materials in the field of energy technologies outlined therein. The research programme includes basic research as well as applied research in the field of innovative materials and their production using plasma processes. This includes novel solutions for the production of complex materials as well as novel combinations of known materials in the form of nanohybrids that exhibit favourable properties in application. The focus here is particularly on the formation of new phases, including non-equilibrium phases, the improvement of crystallinity and phase purity, the increase of interface stability through phase matching and the reduction of segregation, undesired diffusion or interface reactions. Compared to traditional synthesis methods, plasma technology offers the decisive advantage of high process flexibility with simultaneous good control of the properties on the nanoscale. The design of new materials for fuel cells, electrolyzers and batteries requires the combination of several functionalities in one structure. This is achieved by synthesising several crystallographic domains with different functionalities in multilayer concepts or in nanohybrids.

In the synthesis of electrode materials for fuel cells, for example, selective catalytic activity, high electronic conductivity, high ionic conductivity, optimised porosity in terms of mass transport and good chemical stability are achieved through co-sputtering processes. To achieve this, the precursors have to be sustainable. Examples of the material classes are electroceramics, high-entropy alloys and carbon hybridised metal oxides and metals, whereby the manufacturing processes are evaluated for industrial suitability from the outset. As part of the collaboration with the partners of the BMBF WIR! CAMPFIRE alliance, the new materials are used in innovative cell concepts in operation and tested for their suitability on an industrial scale and conclusions are drawn about existing requirements and for process optimisation.

Based on the research results achieved on the laboratory scale in the period 2022/2023, further optimisation work is to be carried out for the applications of electrode materials for SOFC and PEMFC fuel cells, SOEC and PEM electrolysis as well as lithium and sodium ion batteries. As part of the BMWK IGF projects H₂BS and MAXCoat, carbide materials as well as PVD and PEO coating processes for the corrosion protection of metallic bipolar plates and steel components for the hydrogen infrastructure, which will be realised in the future using processes suitable for industrial use.

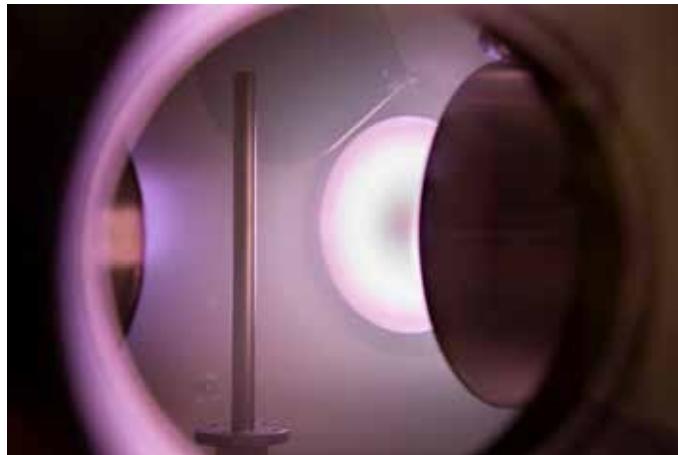


Sputter coating of a tubular substrate with a proton-conducting electroceramic thin film

Application-oriented outlook

Electroceramic thin-film membranes with an oxide perovskite structure were produced for use in solid-state ammonia synthesis for the storage of fluctuating renewable energy using a combined PVD and SLE process. As part of the CAMPFIRE project line CF04 and the IGF project SPUDNIK, a novel SSAS membrane electrode cell concept has been developed. The perovskite thin-film membrane developed as part of the CAMPFIRE project line CF05 will be used in an ammonia cracker together with the partners to increase the start-up capability. Another application of the electroceramic membrane is the HiPowAR membrane reactor developed in the EU FETProActive project. Here, the membrane is integrated into a reactor to realise a flameless combustion process for ammonia. The next steps are aimed at improving the stability of the membrane under high reaction pressure. New material concepts have been developed as part of the BMWK IGF projects Ilisko and VOXCoat for use as electrode materials in the battery. CVD and sputtering processes as well as atmospheric pressure plasma processes are used. The BMWK ZIM cooperation project PtKat and the BMWK IGF projects Magneli-SAFC and CatHEA focus on Pt, Ru

and HEA catalysts. These are hybridised with nanographite domains, copper-based pore templates and tungsten oxide Magneli phases to form high-performance anodes for use in fuel cells and electrolyzers using a roll-to-roll co-sputtering process and an atmospheric pressure plasma. The focus here is on improving performance while simultaneously reducing or eliminating the precious metal content and increasing service life by encapsulating them in electronically conductive and corrosion-resistant nanocontainers. The next step is to upscale the processes in order to achieve higher yields. Reducing material costs and improving performance is also the focus of the CAMPFIRE product line CF06 Microstructured Haber-Bosch Reactor, whereby 3D printed microstructures are developed in direct correlation to the plant technology in the CAMPFIRE Open Innovation Lab (COIL) as part of the BMBF TransHyDE, CAMPFIRE implementation project at the Poppendorf site in collaboration with the joint partners Kellogg-Advances-Ammonia-Process-Katalysatoren. Large-scale test infrastructures for ammonia cracker engines and fuel cell systems of the CAMPFIRE alliance are also implemented in the COIL, with the focus not only on cost and performance requirements but also on the sustainability of the value chains and recyclability with the aim of a sustainable circular economy in future.



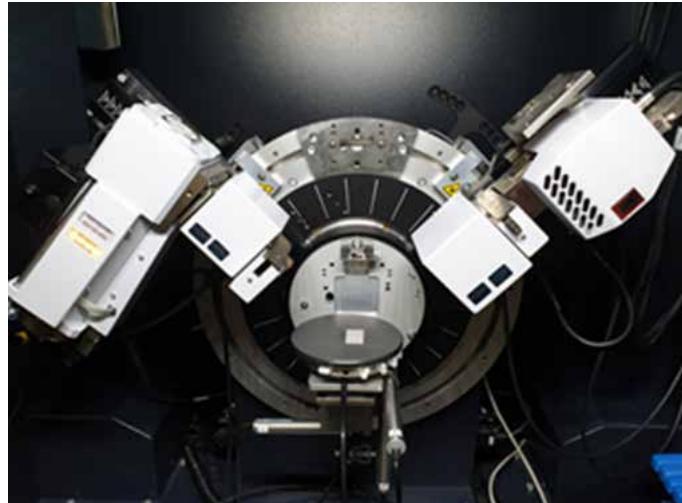
Flow plasma reactor for the production of nanoparticle suspensions using an atmospheric plasma process

Core-funded project

Plasma electrolytic oxidation (PEO) as a phenomenon was first described by Güntherschulze and Betz in 1932 and has been further developed into a versatile and efficient technology for the surface treatment of metallic workpieces since then. The workpiece is exposed to electrical discharges in a controlled electrolyte medium, which simultaneously melt the metal surface and allow oxidation reactions to take place. Coatings with outstanding hardness and adhesion, even on internal surfaces, are the results. At the INP, PEO is of interest in the context of producing hydrogen barrier layers. The process is particularly suitable for coating complex substrates. As part of the work at the INP, a new process for the PEO synthesis of aluminium oxide was developed - a candidate material that has an excellent barrier effect [M. Wetegrove et al., 2023]. The structural investigations of such aluminium oxide layers using X-ray diffraction and electron microscopy as well as the substrate pretreatment using mechanical polishing are examples of the extensive work carried out in the core-funded project. Mechanical polishing of the substrates is often the starting point for coating development, as this ensures a consistent, smooth and defect-free substrate surface. The equipment manufacturer Bühler has a pool of polishing instructions for a wide range of materials, but it is usually necessary to adapt the polishing routine to the respective substrate material with precise documentation of the processing steps. The Bruker D8 Advance is available to researchers for carrying out crystallographic investigations on thin films (see figure, above). Using Grazing Incidence X-Ray Diffraction (GIXRD), the identity and composition of crystalline phases as well as crystallite sizes could be determined by varying the information depth. In addition to the identification of crystalline phases, the calculation of lattice parameters and crystallite sizes as well as the refinement of the complete profile for the calculation of bond lengths, bond angles and defect structure in the crystallite were carried out using Rietveld refinement. This allowed important conclusions to be drawn about correlations between structure and process parameters.

Complementary to the crystallographic investigations, electron microscopic examinations provided a visual impression of the layer morphologies. The Focused Ion Beam (FIB) preparation method allows the production of cross-sections with nanoscale resolution. Scanning electron microscope images of the layer cross-sections using a backscattered electron detector show an order number-dependent material contrast. This method was successfully used to visualise the phase boundary between the substrate and oxide layer and to determine the layer thickness when investigating the layers produced using PEO (see figure).

Electrochemical cells based on ceramic thin films can be used for the efficient production or direct conversion of ammonia into electricity as a new energy storage medium and fuel. In the CF04 project line of the BMBF WIR! CAMPFIRE alliance and the BMWK IGF project SPUDNIK, ammonia solid-state synthesis is developed, which enables the electrochemical production of NH_3 from nitrogen, water and renewable electricity.

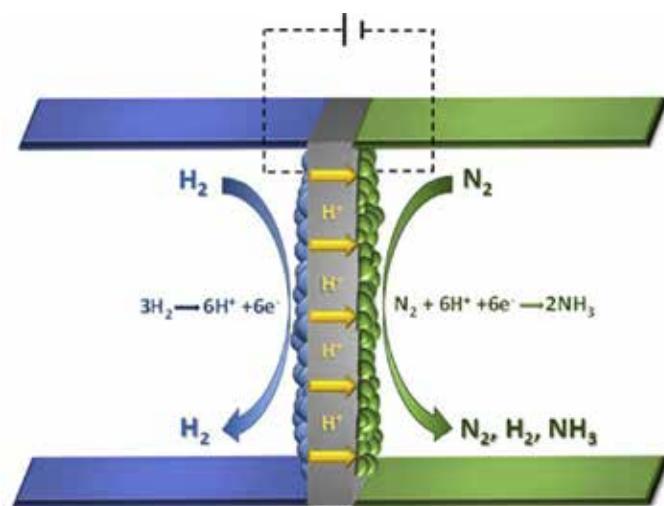


Top: Crystallographic analyses in the Bruker D8 Advance X-ray diffractometer. Bottom: Scanning electron micrographs of a PEO aluminium oxide layer in the FIB cross section

Third-party funded project

To this end, the INP develops a combined process consisting of several subsequent process steps to produce dense perovskite thin films with thicknesses of up to 5 µm on the basis of yttrium and cerium-doped barium zirconate. Firstly, the complex oxides are deposited in a co-sputtering process using a closed-field unbalanced magnetron sputtering (CFUMS) process on the tubular anode substrate. Due to the specific arrangement of the magnetic fields, increased coating rates are achieved in this configuration through a higher ion current density on the substrate. The stoichiometry, which is decisive for the performance and stability of the membrane, can be specifically influenced by varying the precursor targets and the respective process conditions. The sputtered layers are selectively thermally treated using a line infrared laser to achieve homogenisation of the stoichiometry and formation of a crystal phase. This functionality of the membrane is decisive for the ionic conductivity. In the case of doped barium zirconate, phase degradation of barium oxide has to be avoided in order to prevent undesirable cross-doping. As part of the CF04 project line, a comprehensive screening programme was carried out at the INP to optimise the combined sputtering and laser treatment process for the production of proton-conducting perovskite membranes for SSAS, with the main focus on varying the thickness and number of individual layers in correlation with the parameters used in the laser annealing process.

To characterise the performance of the membrane, grain and grain boundary conductivity were characterised using impedance spectroscopy. Thin-film-based membrane electrode assemblies (MEA) were then produced in close collaboration with the partners in the consortium. The INP results, however, show a dense and homogeneous coating of planar and tubular substrates of the MEA, which has a protonic conductivity that is two orders of magnitude better than that of the bulk membrane. As a result, an ammonia production rate of 9.06×10^{-10} mol/(cm²*s) was achieved in cell tests - comparable with the benchmark results of leading research groups worldwide. In order to further develop the technology and cell design, a WIR! CAMPFIRE investment, an innovative high-pressure test stand for the electrochemical characterisation of triple MEA stacks, was implemented and put into operation.



Scheme of solid-state ammonia synthesis

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Overview

The Green Ammonia Materials (GAM) research group researches and develops plasma-assisted synthesis processes for the production of nanomaterials that will be used in the future carbon-free hydrogen-based energy system. Ammonia as a hydrogen derivative and new energy carrier plays a central role for the research group, as it has a strong personnel and strategic link to the BMBF-WIR! alliance CAMPFIRE in the North-East region for the development of green ammonia technologies. Together with the alliance partners, the group's researchers develop important core innovations for the alliance - ceramic and metallic thin films, catalysts, membranes, protective layers, storage materials and redox-active materials for the future hydrogen economy based on ammonia. These are used, for example, in electrolyzers, electrochemical ammonia synthesis, fuel cells, batteries and for thermal material conversions in ammonia crackers and Haber-Bosch processes.

As part of the CAMPFIRE Open Innovation approach, the group focuses its work strongly on the product category "thin films" of the CAMPFIRE alliance and, together with the CAMPFIRE partners, also implements a test infrastructure for power-to-ammonia and ammonia-to-power energy systems at the Poppendorf Technology Centre (PTZ) - Green Ammonia ChemPark on the industrial site of YARA GmbH & Co KG as part of the BMBF lead a TransHyDE CAMPFIRE implementation project. This broad and interdisciplinary approach encompasses chemistry, physics and engineering and enables a goal-orientated, holistic approach and highly dynamic development of the research projects. For example, requirements from the concept development of the microstructured Haber-Bosch reactor in the CAMPFIRE Open Innovation Lab flow directly into the development of the atmospheric plasma process for the synthesis of Kellogg's advanced ammonia processing catalysts. The expertise and know-how of the GAM research group in the field of nanomaterials and plasma synthesis also flow into the development of new battery systems as an important additional technology of the future energy system. Projects of the research group are currently funded within the framework of BMBF WIR!, BMBF TransHyDE, BMWK IGF and Horizon 2020 FETProActiv.

Design and production of complex electroceramic materials

Using process sequences based on PVD, CVD and atmospheric plasma processes, new manufacturing processes for complex materials are developed as the centrepieces of ammonia technologies. These are developed and implemented with regard to phase purity, homogeneity, yield and sustainability. On the atomic scale, the stoichiometry, including doping and defects, is optimised, in order to achieve advantageous functional properties of the materials. One focus is on the development of perovskite proton conductors, oxygen ion conductors, mixed conductors and high entropy alloys. An important part of the researchers' work is also the analysis of phase identity, crystal and defect structure, microstructure and performance using FIB-SEM-EDX, XRD, Raman spectroscopy, physisorption and chemisorption, thermal analysis as well as electrochemical characterisation and analysis of the permeation properties for hydrogen and oxygen.

The research group takes a holistic approach to the development of membrane electrode units based on sputtered thin films on metal-supported substrates, develops new atmospheric pressure plasma-based manufacturing processes for nanoparticle suspensions based on, for example, vanadium oxide-graphene, platinum-magnesium oxide and barium-ruthene-magnesium oxide, which are then formulated and used in wet-chemical coating processes for the respective applications. Another topic is the development of a combined spark plasma and sputtering process for the produc-



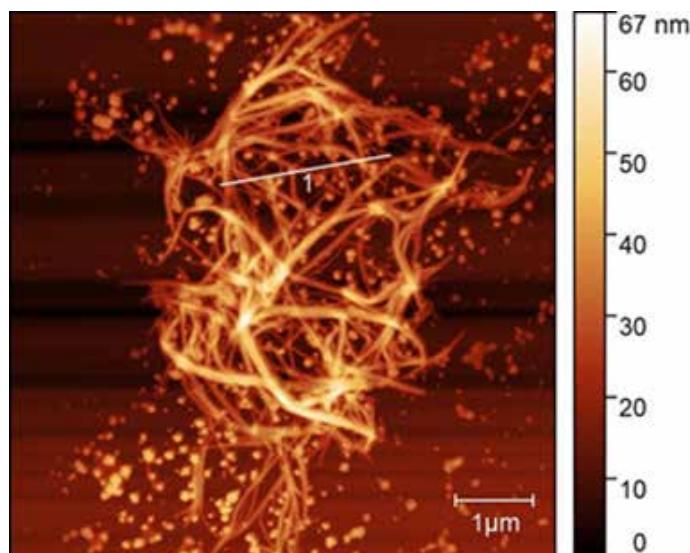
High-pressure test stand for the characterisation of tubular membrane-electrode units based on a sputtered proton-conducting perovskite membrane for use in solid-state ammonia synthesis.

Application-oriented outlook

tion of cost-effective electrode materials based on high-entropy alloys. The particular challenge in the production of complex materials such as perovskites or MAX phases lies in the combination of up to six atoms, which are either arranged in an oxygen, carbide or nitride lattice or form a homogeneous alloy in their metallic form. In recent years, the research group has made very good progress in this field with a process sequence consisting of co-sputtering and laser annealing, with increasing attention also paid to the selection, production and optimisation of the precursors in target form. For the production of nanohybrids that exhibit electrochemical, electrocatalytic or catalytic heterogeneity,

Redox-active hybrid materials

Nanohybrids based on carbon and redox-active components are the key to efficient energy storage in lithium-ion and sodium-ion batteries. The research group has optimised the production process for vanadium oxide and LiS polythiophene. Hybridisation is carried out with commercial carbon nanotubes, nano-onions or *in situ* plasma-generated graphene. In addition, optimised suspensions were synthesised from the nanoparticles using adapted formulation strategies, which are used in state-of-the-art coating processes such as dip coating, screen printing and spraying.



Vanadium oxide graphene nanohybrids for the sodium ion battery for stationary storage of renewable energy.

combinations of magnetron sputtering and chemical vapour deposition or an atmospheric plasma process are used in the GAM research group. In particular in the field of graphene production from organic precursors and the hybridisation of graphene with metallic and metal-oxide nanodomains, the research group has developed new expertise and valuable know-how in reactor technology and reaction control. An important tool here is the statistical design of experiments and the ongoing characterisation of the crystal structure, the microstructure and the specific surface area of the particles produced. To this end, the research group has increasingly worked closely with the University of Greifswald as part of a nanoanalytics seminar organised by the research group across the Greifswald Science Campus.

CONTACT



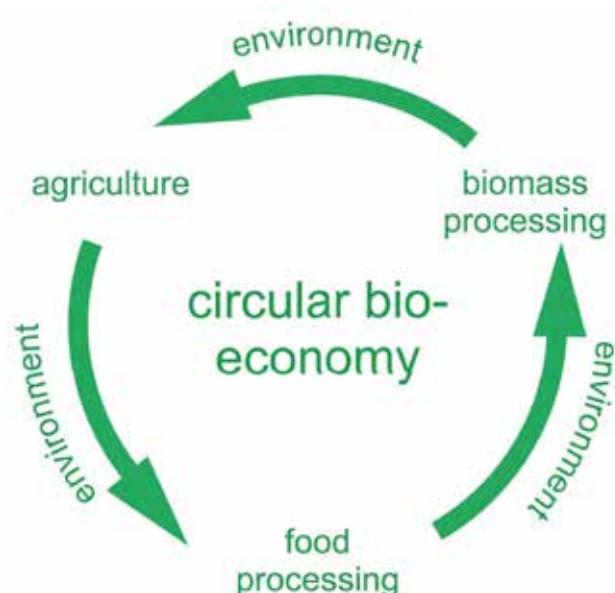
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Overview

The research programme is dedicated to the investigation and the development of plasma methods with potential benefits for the processing and treatment of crops, food products, and biomass substrates. Altogether, these individual topic areas are the basis of a circular bioeconomy, starting with agricultural cultivation and products, which need to be processed for consumer needs or further use, and eventually result in residues, i.e. waste, as a valuable resource that can be exploited and ideally returned towards farming again. Plasma technologies can offer innovations along the entire value chain, which can increase efficiencies and yields, reduce costs for enterprises and consumers, and enable a truly sustainable production with significantly reduced environmental burden. The latter is strongly associated with the prospect of reducing or even replacing procedures that require toxic substances e.g. disinfectants, solvents, or pesticides, and with the possibility of actually decomposing such pollutants, particularly in water. Methods and media of choice for different applications are non-thermal plasmas that are generated in or with air and water by electrical discharges.

The transient chemistry provided by these approaches is in many cases crucial for investigations and developments. For example hydroxyl radicals, produced from water or humid air are, known as potent oxidizing agents and, accordingly, effective in the inactivation of microorganisms and recalcitrant anthropogenic pollutants. On this basis, systems are developed for the degradation of agrochemicals and relevant harmful microorganisms in food processing and other industries. The goal is an effective wastewater treatment as well as an efficient reuse of water by combining plasma with other methods. This way freshwater intakes can be reduced and resources, such as rainwater drainage can be, made available for circular water systems for indoor aquacultures or farming. An application for the degradation of pharmaceutical residues and inactivation of antibiotic-resistant bacteria in wastewater from hospitals is evident. Plasma-treated water offers also new possibilities for the cultivation of crops.

The perspectives are to address phytopathogens and simultaneously stimulate plant growth and even induce tolerances against abiotic stress, e.g. drought and flooding. Foodborne pathogens can likewise be confronted and specific applications, in particular for the sanitation of fruits and vegetables by plasma-treated water or by plasma-treated air, have now reached a level of maturity close to markets. A treatment of seeds by plasma treated air has been shown not just to improve seed hygiene but also to stimulate germination. Reactive nitrogen species are held responsible. Plasma processes in the absence of oxygen are in particular relevant for the treatment of organic wastes, e.g. from food, lop, or manure. These biomass substrates are generally of inferior value for biogas plants since they are difficult to degrade for subsequent fermentation. However, with a combination of plasma and ultrasound treatment, it was possible to considerably increase the biogas yield of such substrates. Concurrently, discharges, submerged in microalgae suspensions, have been found successful for the extraction of valuable compounds. New topics are emerging continuously, expanding current research activities. The recovery of appreciated substances and the targeted transformation of organic matter and chemicals in liquids by oxidative and reductive processes are notable.



Plasma methods provide innovations along the entire value chain of a circular bioeconomy. Disinfection and decontamination provide safer products. Alternatives to pesticides protect the environment and can secure harvests. Waste can be exploited as a valuable resource.

Application-oriented outlook

The research programme investigates a large variety of different plasma systems, which include dielectric barrier discharges, nanosecond pulsed high-voltage discharges, and discharges operated by microwaves. Besides a fundamental understanding of underlying processes and mechanisms, the inherent goal always is to find the best technology for a specific application and need (and not the other way round). Hence, the development of systems "From the idea to prototype" is pursued with a focus on improvements and advantages for individual processes and their requirements. Advances in the different areas are motivated by steadily increasing technology readiness levels. For applications of plasma methods in agriculture methods have mostly been validated in the laboratory so far. First trials in the field are commencing. Water treatments have already been validated in relevant environments, which provided valuable insights into actual requirements, including cost efficiencies. Technologies for the degradation of biomass have likewise been successfully tested in actual biogas plants.

A rather advanced development is the application of plasma-treated water in food hygiene, specifically for the sanitation of fresh-cut lettuce. Contaminations of leafy greens, including ready-to-eat salads, are a frequent cause of serious outbreaks of food poisoning, even resulting in fatalities. Current washing procedures are apparently not adequate to address the problem. Conversely, the studies have conducted in the research programme, shown that plasma-treated water, which is used especially for the final steps of a washing process, can significantly reduce the microbial load. This

helps to extend shelf life and foremost benefits consumer safety. Based on the experience in different previous collaborations, KRONEN GmbH and INP together with GARTENFRISCH Jung GmbH and the Leibniz-Institute for Agricultural Engineering and Bioeconomy joined in the development of a prototype for a salad washing machine. System and approach have been tested for one year in a commercial setting. The project SPLASH was funded by the Federal Ministry of Food and Agriculture. The outcome permits a close to fully hygienic washing process and at the same time conserves water. Although it has been successfully tested for an operation with plasma-treated water with proven advantages, this commercial use is not yet possible until an admission by European and German authorities has been granted. This requires studies and their documentation, specific to the treated product, which are currently conducted and supported by the necessary investigations. Regardless, other candidates, i.e. fruits and vegetables, are already considered to expand the scope, based on the experience with lettuce washing. However, if a wet sanitation is not needed or possible, exposure to plasma-treated air, as produced by a process patented by the INP, can be a viable alternative. The technology has already been demonstrated on a pre-commercial pilot scale with an implementation in the overall process for the handling of apples concerning preservation and storage. The next steps in the development have to concentrate again on studies that are necessary to obtain accreditation for the method and the particular application. This is also the objective for other products, e.g. herbs and spices, besides the identification of possibly different operating parameters and the integration in existing processes.



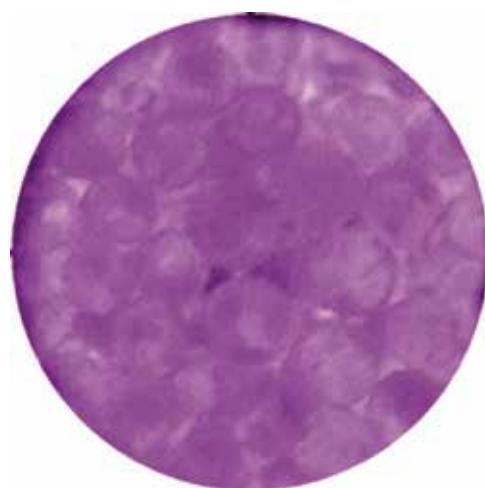
Plasma-treated water for the sanitation of fresh-cut lettuce in a commercially available washing machine. Microbial loads could be significantly reduced and this way a safer product for consumers is provided. Market introduction is pending approval of the method.

Core-funded project "Chemical transformations in liquids by plasma processes"

The applications, pursued in different projects by the research programme, are almost exclusively based on the chemistry provided in liquids by the exposure to a plasma. Therefore, the ambition of the core-funded project is to support these applications by fundamental studies on respective processes. So far, the most important liquid is water, while the most relevant processes are the degradation of anthropogenic pollutants, the inactivation of microorganisms, and the disintegration of plant biomass or microalgae. In most cases, these objectives can be related to the oxidation of targeted compounds and biomolecules. Reactive oxygen species, foremost hydroxyl radicals, are responsible. Therefore, the formation of hydrogen peroxide, as the final reaction product of hydroxyl radicals, was quantified with respect to characteristics of discharges in water and linked to hydroxyl radical formation. The active volume of the discharge, described primarily by the extent of plasma channels, was found crucial. Hydrogen peroxide concentrations increased quadratically with propagation time but surprisingly not depending on water conductivity. Notable, production rate and efficiency doubled when the pulse duration decreased from 300 to 100 ns, resulting in the highest hydrogen peroxide production rate of 9 g/kWh reported so far for discharges in water. The studies confirmed assumptions on the efficiency, especially of 100-ns high-voltage pulses, which were already observed for the degradation of pharmaceutical residues, and now provide further guidance for applications.

Another study focused on the time course for the generation of peroxy nitrous acid from hydrogen peroxide, which is held predominantly responsible for the inactivation of microorganisms in aqueous solutions. The buffer capacity of the solution treated with plasma was found critical for the accumulation and permanence of the transient compound. Higher concentrations could be accumulated during the plasma exposure for liquids with a higher buffer capacity. This allows continued production of peroxy nitrous acid even when the buffer capacity is depleted. Conversely, the antimicrobial efficacy can be optimized by adjusting treatment

conditions. Implementation of the findings permitted an inactivation of even dormant *Bacillus atrophaeus* spores by 3.8 orders of magnitude. Besides for degradation and inactivation of pollutants and microorganisms, chemical transformations have been investigated for a targeted chemical synthesis. In particular, valuable organic compounds can be produced in an environmentally friendly manner. The formation of methoxylated and hydroxylated products as well as dimers was shown for 2,5-dihydrobenzoic acid derivates in aqueous solutions at atmospheric pressure and room temperature without any catalysts. Different treatment modalities resulted in the formation of stable benzoquinoid products, which are the basis for fine chemicals, polymers, or building blocks for pharmaceuticals. The described possibilities of targeted transformations recommend the method as a novel approach in green chemistry. A transformation of particular interest is the conversion of carbon dioxide. A novel approach is the combination of plasma with functional biological matter. Therefore, cells or cellular components have to be introduced into the plasma. First studies showed that operating conditions can be found, which doubled the conversion in comparison to the plasma treatment alone.



Glass beads were coated with material from carbon dioxide converting cell species as filling of a packed-bed dielectric barrier discharge configuration. The plasma provides a reaction chemistry, which supports the conversion of carbon dioxide by the functional coating.

Third-party funded projects for the development of plasma methods for agriculture

The development of plasma methods for agricultural applications could be considerably advanced in several projects within the encompassing frame "Physics for Food", funded by the initiative "Wandel durch Innovation in der Region" from the Federal Ministry of Education and Research. The consortium of more than 60 funded and associated partners from research and practice is led by the University of Applied Sciences in Neubrandenburg and the INP. From 2018 to 2025 methods will be developed to replace and reduce agrochemicals and their environmental impact in different projects. The INP focuses on different concepts for a direct plasma treatment or an indirect treatment, i.e. with plasma-treated air (PTA) or water (PTW). Within the project "Physics for Seeds" possibilities were studied to achieve an inactivation of seed-borne phytopathogens without chemical dressing. The results show that a plasma treatment is as effective as a treatment by electron beams. The latter is a method already introduced into markets. Pathogens for different molds and rods that are relevant for barley, rape, and lupine could be successfully inactivated by plasma methods. In field trials, no differences in germination and harvest yields were observed in comparison with conventionally treated seeds. In fact, for the plasma treatment, a slightly accelerated early growth also hints at a strengthened biochemistry. The studies continue in the follow-up project "Physics for Seed Treatment", which is expanded on pathogens and seed species, e.g. fava bean, and exploits a combination with growth-promoting bacteria adhering to the seed coats. In the project "Physics for Crops", followed by "Physics for Cropping Systems", potentials are investigated to promote and protect the growth of crops by replacing or at least complementing the use of pesticides by plasma treated water. Nitrogen fixation in the water by plasma treatment and a direct stimulation of metabolic processes are responsible for accelerated growth. An induced higher resilience of plants against droughts and floodings is particularly interesting. Plants of the blue lupine showed higher biomass parameters and higher proline content in comparison to the untreated control after an induced drought of two weeks for priming with PTW, confirming the adaption on a biochemical level. Other biomarkers were likewise affected also for flooding.



Field trials investigating the benefits of plasma-treated seeds and the application of plasma-treated water to promote the growth and resilience of crops have been conducted in more than eleven locations across Germany for at least three growth seasons and are ongoing.

Reducing environmental burdens, especially on water bodies, motivated the project "Physics for Environment", which was expanded in scope by "Physics and Ecology". By a combination of conventional and novel methods, including plasma, a comprehensive water treatment could be demonstrated, which targets especially agrochemicals. Solutions are now developed for different needs in the processing of agricultural products, which aim at water reuse and uncontaminated wastewater. Another focus is on improving or even restoring soil health by either treating contaminated soil directly or with plasma-treated water or processed organic waste e.g. manure.

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Plasma Process Technology

The expertise of the Plasma Process Technology department covers the areas of plasma-chemical gas conversion such as CO₂ reduction, biomass treatment and plasma-assisted vacuum processes for the production of highly porous layers for electrocatalysis.

For the decomposition and reduction of CO₂, various arrangements of dielectric barrier discharges (DBDs) such as single-stack, multi-stack and coaxial designs were systematically investigated with regard to the electrical properties and CO formation under variation of the geometric parameters. These studies provided information about the electrode coverage of the discharge and the capacities and discharge powers could be quantitatively determined. The behaviour of partial area discharges could be described with corresponding equivalent circuits.

When using coaxial DBD reactors, an increase in CO formation due to an increase in the pressure of the CO₂ plasma was demonstrated for the first time. The additional introduction of a CeO₂ catalyst into the discharge gap increases the energy yield of CO generation.

In contrast to DBD arrangements, barrier corona discharges can reduce the voltage amplitude required for plasma generation due to the constructively generated field enhancement.

Increasing the process pressure does not have a strong negative effect on the energy yield of CO₂ splitting.

The effect of the polarity of high-voltage pulses in the nanosecond range on CO₂ splitting was also investigated using pulsed DBDs. Operation with high-voltage pulses of positive polarity showed a higher CO₂ conversion compared to negative polarity. With the help of these discharges, enzyme-catalyzed CO₂ reduction with hydrogen could also be directly supported.

For the treatment of biomass, investigations using a process consisting of a combination of a microwave discharge and an ultrasound source with a common field of action were started. The focus is on the influence of plasma-ultrasonic treatment on biomass conversion, methane production and process stability in the anaerobic fermentation of various residues, recovery of essential elements, such as phosphorus and hydrogen production.

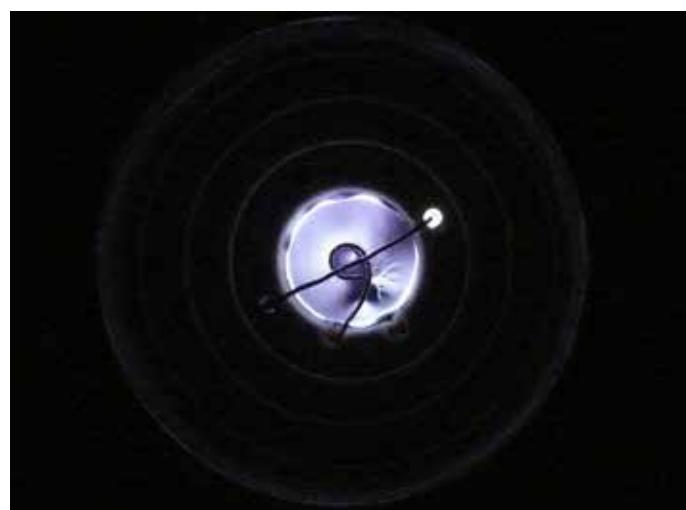
In acidic water electrolysis, iridium-containing catalysts are used for oxygen evolution reactions at the anode. For this purpose, an industrially suitable production method based

on PVD (physical vapor deposition) processes and test methods that realistically describes the behaviour of the catalyst were developed. In particular, a method for testing gas diffusion electrodes in a half-cell arrangement was introduced. Special self-supporting Ir-Co catalysts with low Ir loading, which were produced by PVD, showed more than ten times higher oxygen evolution mass activities compared to a commercial, unsupported IrO_x nanoparticle catalyst. These results support the founding of a spin-off in the field of gas diffusion electrodes for water electrolysis.

Technologische Ausstattung:

Plasma sources for chemical synthesis:

- Dielectric barrier discharges
 - Single stack reactor
 - Multistack reactor
 - Coaxial arrangements for high-pressure syntheses



Plasma source for plasma-electrochemical processes

Biomass treatment:

- KombiMax demonstrator; includes two 1 kW ultrasonic sources, a 500 W microwave source and a 10 L recipient
- Microwave generators in the 1-3 kW range
- Test reactors for biomass treatment on a laboratory scale (2 L volume)
- Agilent 8860 GC system
- Biogas batch fermentation system, AMPTS III

MEA production and testing:

- ND-SP Ultrasonic Spray Coater® 11/3 fully integrated, X-Y working area of 300mm x 300mm
- LaboPress P150H, 150mm x 150mm
- quickCONNECT fixture qCf, active area: 25 cm²

Experimental equipment for plasma engeneering

PVD, PECVD:

- PIAD vacuum coating system, M 900
- UNIVEX 400 with loadlock

Plasma technology for powder modification:

- Rotary drum reactor, HF or microwave excitation, vacuum process for activation or coating (PECVD) of bulk materials

Outlook on future priorities

- Plasma-chemical material conversion
 - Reduction of CO₂ with H₂ to energy sources such as methanol or formic acid
 - Support of enzyme-catalyzed syntheses by plasma processes
 - Recycling of polymers
- Combination of plasma and electrocatalysis
 - Investigation of the synergy of plasma-chemical and electrochemical processes in the joint field of action
 - Synthesis of ammonia and other hydrogen carriers
- Combination of plasma and ultrasound for the treatment of biological substrates
 - Increasing the efficiency of biogas processes
 - Improving process stability in the anaerobic fermentation of residues
 - Effects of plasma ultrasound on various raw materials

- Investigation of the influence of plasma ultrasonic treatment on the microbiome along the entire process chain from the raw materials to the anaerobic digestion process to the fermentation residues
 - Phosphorus recovery from biomass
 - Nitrogen enrichment
 - Hydrogen production

- Scaling up methods for generating highly porous catalyst layers for electrocatalysis



Spark discharge in water for biomass treatment

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Bioengineering

The Plasma Bioengineering department combines expertise in the development of processes based on the interaction of plasma with biological material.

To this end, expertise is provided in the development, co-ordination and diagnostics of special plasma sources optimized for the task at hand as well as in the diagnostics of the treated biological system.

In addition, the optimization of the necessary procedures is another focus.

Current thematic priorities are the development of plasma processes for hygienisation in the post-harvest area with a focus on the agricultural and food sector as well as innovative methods for process analysis and monitoring. Here, the applicability and integrability into the industrial production environment is important in order to realize the potential transfer to industry.

Examples of the Plasma Bioengineering department's current activities include:

- the development of a hygienisation process based on reactive nitrogen species (RNS) that enables both dry and wet treatment by means of a basic device,
- the development of optical sensors for process monitoring based on special diode laser systems and
- the optimization of laboratory samples to industrial standards.

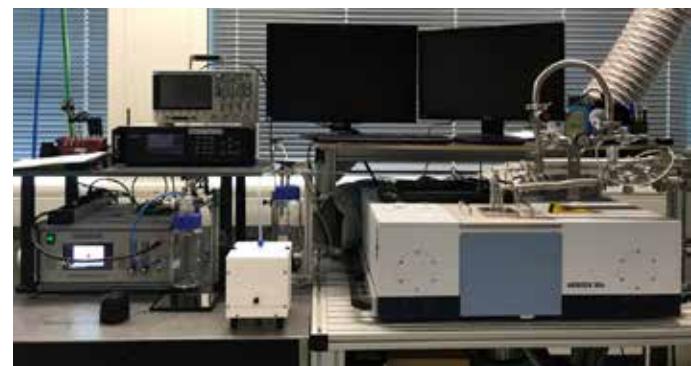
The application-oriented research work is mainly carried out on the basis of joint projects with significant industrial participation.

Technological equipment

Auxillary Decontamination Unit (ADU)

Two-stage self-igniting atmospheric microwave-excited plasma torch for plasma processed air (PPA) generation with process control for operating peripheral devices, capacity: 100 slm. Units for the generation of plasma treated water (PTW), total capacity: 2,000 l.

Various peripheral devices for dry and wet treatment; e.g., bulky goods (e.g. seeds, herbs, spices), fresh/ fresh-cut fruits and vegetables as well as meat/fish products up to 200 kg batches.



Setup for gas diagnostics of plasma-processed air in the laboratory

MiniMIP

Small microwave-excited plasma torch for chemical diagnostics and biological applications.

Standard microbiological methods

- Proliferation assays
- Live-death determination
- Biofilms- Microorganisms of risk groups 1 and 2

Standard methods of quality monitoring

- Water content
- Sugar content
- Colour change (laboratory system)
- Texture measurement



Food-associated microbiology - new labs at Centre for Life Science and Plasma Technology (Z4)

Optical measurement equipment

- Optical emission spectroscopy (OES)
- Fourier transform infrared spectroscopy (FTIR) thermometry
- Laser diode absorption spectroscopy

High-frequency measurement equipment

- Various spectrum and network analysers from 10 Hz to 50 GHz
- Microwave interferometer

Flow simulation

- Numerical flow simulation based on StarCCM+

CAD design

The following topics are the subject of current developments in Plasma Bioengineering:

- hygienisation of seeds and sanitation of fresh germination stimulation of seeds
- inactivation of human pathogens (especially zoonotic pathogens) using plasma technology on sensitive surfaces

- developments to increase the shelf life of fresh food by reducing phytopathogens
- studies on food quality
- research on the modes-of-action between non-thermal plasma and biological matrix

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Overview

Together with the Fraunhofer Institute for Large Structures in Production Engineering (IGP, Rostock) and the Leibniz Institute for Catalysis (LIKAT, Rostock), we at INP want to play a pioneering role in the development of cost-effective and efficient hydrogen technologies. With the support of the Ministry of Economics, Infrastructure, Tourism and Labour of Mecklenburg-Vorpommern, we will establish the Power-to-X plasma development platform within the "Forschungsfabrik Wasserstoff MV" in the area of Rostock.

The aim is to develop new technologies in the field of renewable energies and alternative energy sources (such as synthetic methanol or green kerosene) as well as to approve their efficient application in practice.

The INP focuses on plasmalysis processes, which require less electrical energy to split methane into hydrogen in comparison to the electrolysis process. Plasmalysis is therefore a promising alternative as well as key technology for producing emission-free hydrogen economically on a decentralized basis and significantly increasing its yield while reducing the consumption of renewable energies.

In a plasmalysis process the hydrogen carrier (e.g. biogas or LNG) is decomposed into hydrogen and solid carbon with the help of plasma. As long as the carbon remains permanently bound, plasmalysis offers a real carbon sink, when using biogas and renewable energies.

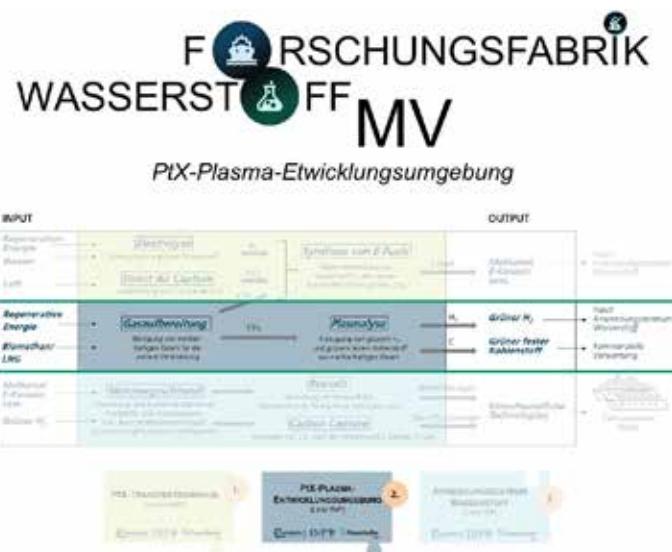
The focus of the project is on preliminary research for innovative plasmalysis technologies for decentralized dynamic hydrogen supply. The technical implementation will take

place step by step in order to minimize development risks and still ensure the fastest possible market ramp-up.

The first unit will be developed at the INP in 2024 and 2025 and set up at the Center for Life Science and Plasma Technology (Z4) in order to start simultaneously with the larger unit and transfer findings to it. The installation of the second unit will begin in 2026 in order to start commissioning in Rostock at the end of 2027.

The aim of the Power-to-X plasma development platform is to develop technologies as a basis for commercially viable, scalable, standardized modules in collaborative research projects with industry

These modules can be used in biogas plants, shipping, LNG terminals or small-scale decentralized H₂ supply systems.



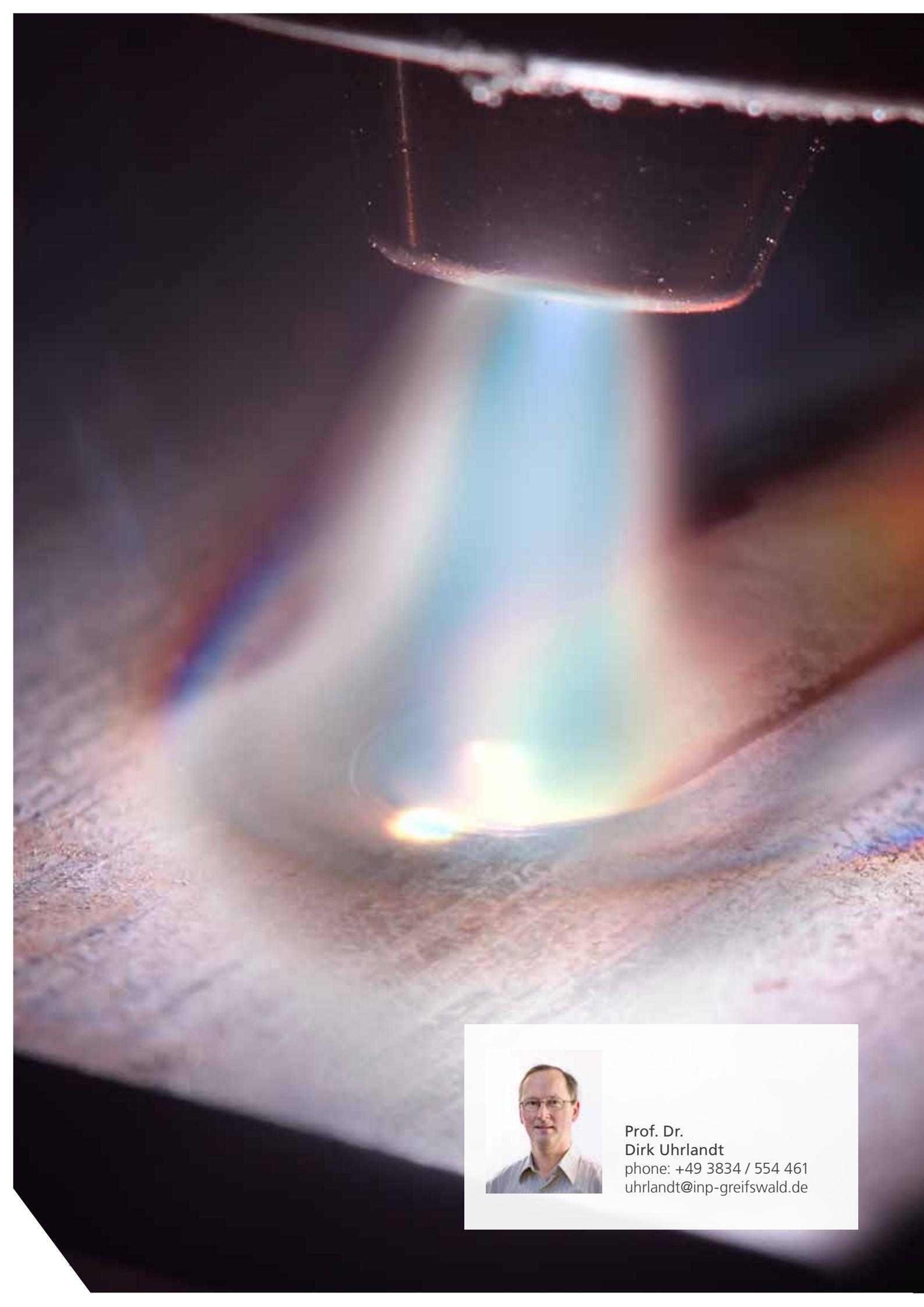
Key topics and schematic diagram of the cooperation of the sub-projects within the Forschungsfabrik Wasserstoff MV



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RESEARCH DIVISION

PROCESS TECHNOLOGY

Overview

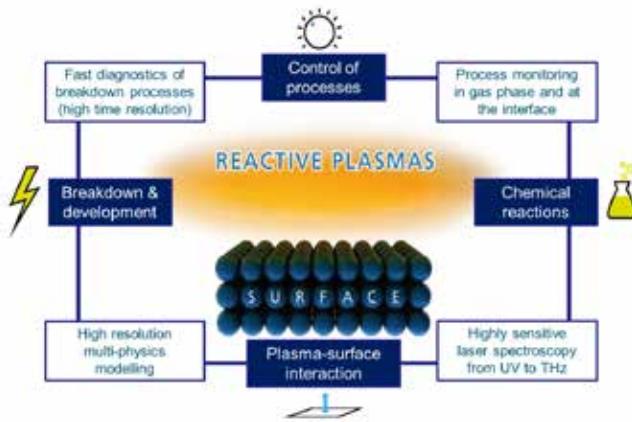
The “Process Technology” research division focuses on the further development of specialized diagnostics and simulation for application-oriented research on plasmas. Plasma technology topics are bundled, in particular for production, process and energy technology. The Plasma Chemical Processes research programme investigates the physics and chemistry of reactive non-thermal plasmas and develops methods for their measurement, simulation and control. This results in efficient process control and greater process reliability. The Thermal Plasma Technologies research programme focuses on electrical power engineering, high-voltage engineering and process engineering using electric arcs. The aims are to increase the performance and reliability of power supply components and to develop environmentally friendly switch technology. Both research programmes are characterized by close cooperation with industrial partners, including in bilateral projects, which benefit from the use of innovative diagnostics and models.

Research Programmes of the Division:

Plasma Chemical Processes

Thermal Plasma Technologies

Overview



Issues and core topics of the research programme
"Plasma Chemical Processes"

The research programme Plasma chemical processes focuses on the physics and chemistry of reactive plasmas, develops new concepts for plasma reactors as well as approaches and methods for controlling plasma chemical processes.

Therefore, the composition of various plasmas, i.e. the concentrations of charged and neutral plasma components, the energy distribution in the plasma, its emitted radiation and the interaction of the plasmas with its boundaries are analyzed and investigated. Among other things, the development of new methods for controlling plasmas for surface treatment and plasma-chemical gas conversion are in the foreground.

The most modern and sensitive methods of infrared absorption spectroscopy are available. In addition, fast imaging methods can record the formation of the plasmas, the electrical breakdown and the discharge regimes, which can be used to study the correlation between discharge physics and plasma chemistry. Modelling and simulation tools are also applied for the detailed analysis of multiphysical processes.

Fields of Application

Non-thermal atmospheric pressure plasmas:

Non-thermal plasmas, which can be operated at atmospheric pressure, are an important technology today. They are used, for example, to modify sensitive surfaces, in the treatment of gases and in biomedical applications. The research programme investigates, among other things, plasma jets and barrier discharges, which can be found in a variety of industrial processes. On the one hand, the processes of plasma formation, i.e. the mechanisms of electrical breakdown, are of interest, and on the other hand, the determination of the reactive species and the identification of the essential plasma-chemical gas conversion processes are in the focus.

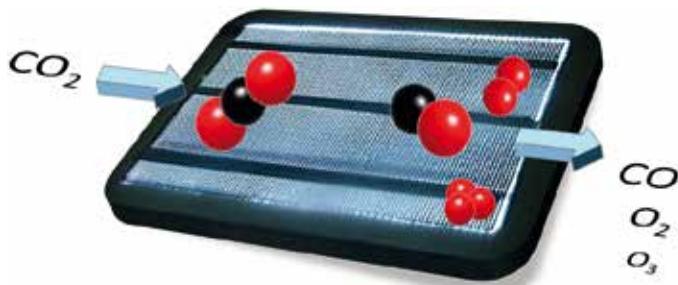
Plasma reactors for Power-to-X and clean air:

Non-thermal plasmas at atmospheric pressure are state of the art, e.g. in air pollution control. We also research the conversion of gases, such as the greenhouse gas carbon dioxide, which should lead to new concepts for Power-to-Gas or Power-to-Fuel technologies. The development of new plasma reactors is based on a sound understanding of these plasmas using experimental methods and multidimensional plasma modelling. In addition, we develop scaling concepts to enable a successful transfer to industrial practice.

Prozess control in industrial plasmas:

Plasma technology plays a key role in the manufacturing of microelectronics. However, its many applications are not yet fully understood in terms of the chemical and physical aspects. These are important for optimizing processes, for example, for smaller and faster circuits. In addition, process control becomes increasingly important in the semiconductor industry so that the duration of the processes and the quality of the products can be optimized. In particular, the detection of atoms, e.g. oxygen or fluorine atoms, is of great importance, but has so far failed due to the lack of suitable methods for their detection in industrial practice. In addition to the development of highly sensitive diagnostics, fundamental questions related to plasma-surface interactions are investigated at the fundamental level. The research is in tight connection with simulations.

Application-oriented outlook



Conversion of the greenhouse gas carbon dioxide (CO_2) in the plasma of a planar barrier discharge into carbon monoxide (CO), oxygen (O_2) and ozone (O_3)

The work in the research programme is aimed, among other things, at new processes for the direct plasma-assisted and plasma-catalytic production of basic chemical substances from simple raw materials.

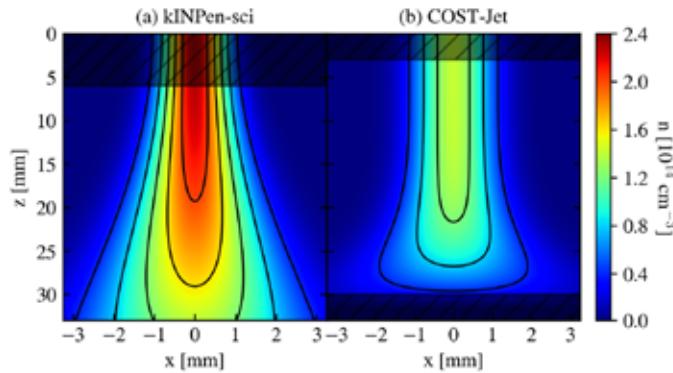
In order to produce chemical substances, carbon-containing starting materials, primarily the greenhouse gas carbon dioxide, are to be converted into other chemical compounds by use of plasmas. These substances serve as basic or starting materials for subsequent synthesis processes or are further converted in the plasma itself. Plasmas offer the special possibility of producing chemical substances efficiently and locally "on demand" using volatile electrical energy from renewable sources. Various plasma reactors for splitting carbon dioxide into carbon monoxide as a starting material for other chemicals are investigated. In addition to chemical material conversion, which is studied using gas analysis, extensive electrical measurements are carried out. Electrical equivalent circuit models make it possible to determine the plasma power and predict plasma operation under changing operating conditions and parameters of the discharge arrangement.

In 2022, the WIR project "biogeniV", funded by the Federal Ministry of Education and Research, entered its first implementation phase with its alliance of more than 15 regional and supra-regional partners. In 2023, a project was launched as part of this first implementation phase that devotes to the production of biomethanol from biogenic carbon dioxide from biogas plants. The aim is to combine catalytic processes with plasma processes and state-of-the-art membrane technology. The goal is to create a new technological option for biomethanol production that can be used decentrally, e.g. at biogas plants. In addition to this new opportunity for the bioeconomy, which also addresses the challenges of the energy transition, this research field also addresses the topic of the so-called electrification of the chemical industry.

The complex chemical nature of molecular plasmas poses a challenge for conventional absorption-based laser diagnostics. For example, spectrometers based on low-bandwidth cw lasers can only measure a few transitions for individual molecular species. With careful selection of the spectral range, several species can be measured simultaneously, but the problem of cross-sensitivity can prevail. In contrast, broadband spectrometers such as Fourier transform infrared spectrometers (FT-IR) and dispersion-based spectrometers cover a much wider spectral range and can measure multiple species in the plasma almost simultaneously. However, FT-IR spectrometers that use incoherent light sources have a limited spectral resolution. Another challenge in absorption spectroscopy of molecular plasmas is the lack of accurate spectroscopic parameters. To address these challenges, frequency comb-based spectroscopy techniques for broadband, fast and precise measurements of absorption spectra of molecular species in plasmas are being developed and applied. These activities also broaden the research programme with regard to methods for the investigation and control of industrial plasma processes.

Core-funded project

“Plasma chemistry”



Density distribution of hydrogen peroxide in the effluent of different plasma jets. (Harris, Krös et al. Plasma Sources Sci. Technol. 32 (2023) 115010)

Despite the worldwide research activities in cold atmospheric pressure plasma jets and their applications in surface treatment and medicine, there are still open questions about fundamental aspects of these plasma sources. For example, it is not yet sufficiently understood which reactive components are formed and how they are generated and destroyed. Hydroxyl radicals, atoms of oxygen, nitrogen or hydrogen and above all stable reactive components such as hydrogen peroxide, are of particular importance. The latter also interacts with the treated surface or wound and thus influences the plasma effect. In addition, it has not yet been sufficiently understood how the composition of reactive species can be controlled or even optimized for a specific purpose. Accordingly, there is great interest in measuring absolute and spatially resolved distributions of the densities of reactive species in the effluent entering the ambient air at the nozzle outlet of the plasma source.

The research programme Plasma Chemical Processes and in particular the Plasma Diagnostics department develop, optimize and apply diagnostic methods to overcome these challenges. The Plasma Modelling & Data Science department is dedicated to the simulation of these plasmas in close coupling with the experiments.

Cavity Ring Down Spectroscopy is a method that offers high sensitivity and spatial resolution. It is named after the used optical cavity into which a laser beam is resonantly coupled. The species to be detected selectively absorb part of the laser beam, whereby the considerably longer absorption length due to the resonance is the reason for the outstanding sensitivity of this method. The local densities are determined from the temporal decay of the light intensity after the laser radiation is switched off. The spatial distribution of the absorbing species can be obtained by measuring the displacement of the plasma source in relation to the laser beam at various points.

Using the kINPen plasma jet operated in helium as working gas, the local density distribution of hydrogen peroxide could be determined. In collaboration with the University of York, a comparison was made between two helium plasma jets with different geometries.

It was shown that the different geometries of the plasma nozzles result in significant differences in the flow dynamics and thus the mixing with the ambient air into which the helium and the plasma enter as the so-called effluent. This leads to different local distributions and maxima of the density of the reactive components. For example, the maximum density of hydrogen peroxide measured for the kINPen is approximately twice as high as in the COST-jet. For both plasma jets, it can be stated that the hydrogen peroxide mainly occurs within the plasma nozzle or only a few millimetres after it exits.

In addition to the above-mentioned species, which are mainly caused by minor impurities in the working gas (usually the noble gases argon or helium), complex plasma physics and chemistry also take place in the working gas itself. In addition to the ionization of the noble gas atoms, their electronic excitation takes place, whereby few energy levels are metastable, i.e. they store their excitation energy for a relatively long time and can thereby contribute to the formation of reactive species, for example.

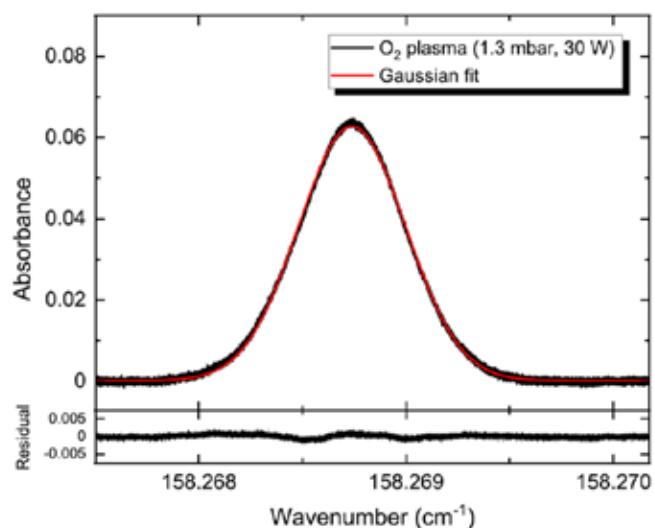
The argon excimer is another species that plays an important role in the formation of reactive oxygen and nitrogen species. The special feature of excimers ("excited dimers" or "excited trimers") is that these instable molecules only exist in an electronically excited state and decay under emission of photons. The argon excimer emits photons of extremely short-wave vacuum ultraviolet radiation playing a role in the application.

Metastable argon atoms and argon excimers have also been successfully investigated using laser diagnostics at the INP. The latter could be quantitatively measured in the effluent of the kINPen in argon using Cavity Ring Down Spectroscopy and show much different spatial distributions of their density than the previously measured species such as hydrogen atoms or hydrogen peroxide. This is subject of further research activities at the INP.

To simulate weakly ionized, non-thermal plasmas in argon at moderate temperatures, an extended reaction kinetic model was developed. It considers 23 different species, including electrons and atoms in the ground state, one atomic and one molecular ion, four excited molecular states and 15 excited atomic states of argon. It comprises 409 collision processes and radiative transitions as well as most-recent data on the electron impact cross sections. The results of time- and spatially-resolved fluid modelling of the discharges show a better comparability with experimental results and thus, enable more precise statements on discharge evolution and plasma chemistry.

Terahertz absorption spectroscopy has been developed and validated as a new diagnostic method at the INP. Terahertz (THz) radiation lies in the electromagnetic spectrum between microwaves and infrared radiation. Its absorption

in plasma enables the highly sensitive detection of certain atoms and molecules as well as electrons and ions. The densities determined in a capacitively coupled high-frequency oxygen discharge at low pressure show very good agreement with laser-induced fluorescence as one of the previous standard diagnostics and demonstrate the great potential of THz-based diagnostics.



Absorption profile of a fine structure transition of oxygen atoms in an oxygen plasma at 1.3 mbar and a plasma power of 30 W (Wubs et al., Appl. Phys. Lett. 123, 081107 (2023)).

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Plasma Diagnostics

The application-oriented research activities in the department Plasma Diagnostics are centered on investigations for process monitoring and control, in particular for molecular plasma processes. Both fundamental and application-relevant aspects in the field of plasma chemistry and process technology are addressed. The focus is on the time- and spatially resolved, qualitative and quantitative chemical analysis of molecular plasmas, both in the gas phase and on surfaces.

The department of plasma diagnostics works with state-of-the-art methods and is constantly expanding the existing expertise as well as the spectrum of measurement devices and methods, especially laser-based plasma diagnostics. Spectroscopic questions in the spectral range from ultraviolet to Terahertz are addressed.

The application of state-of-the-art methods of plasma diagnostics is the key to understand complex plasmas. Molecular plasmas which contain a large number of different species are characterised by a variety of interesting and valuable properties. Their wide range of technological applications extends from resource-saving surface treatments, for example in the semiconductor industry or for the production of surface layers using plasma nitrocarburising, to disinfection and sterilisation processes, exhaust gas purification and gas scrubbing, particle degradation and the treatment of water, air and hazardous waste.

Plasma diagnostics enables the absolute measurement of energy and temperature distributions as well as densities of stable and transient species in the plasma by means of probe diagnostics, absorption spectroscopy, and optical emission spectroscopy allowing the determination of all relevant chemical processes.

In addition to the characterisation of plasma processes to answer fundamental and application-relevant questions, diagnostic methods for monitoring and controlling technological plasma processes are applied and further developed in the department. The use of ultra-modern frequency comb systems (FCs) in the mid-infrared spectral range will open up a completely new approach to the elucidation of plasma-surface interactions. FCs will be used as radiation sources in broadband, resonator-based, direct frequency comb spectroscopy (CE-DFCS).

This method will allow a large number of transient reactants to be detected simultaneously in the immediate vicinity of the surface. To this end, new detection methods have been developed in recent years that utilise FCs as light sources. This applies to both frequency comb-based Fourier transform spectroscopy and a Virtually Imaged Phased Array (VIPA) spectrometer.

In a project funded by the Federal Ministry of Education and Research, a new air-spaced VIPA etalon and a compact and mobile VIPA spectrometer have been developed. The system can be used in a wide variety of application scenarios for the highly sensitive detection of molecules in plasmas.

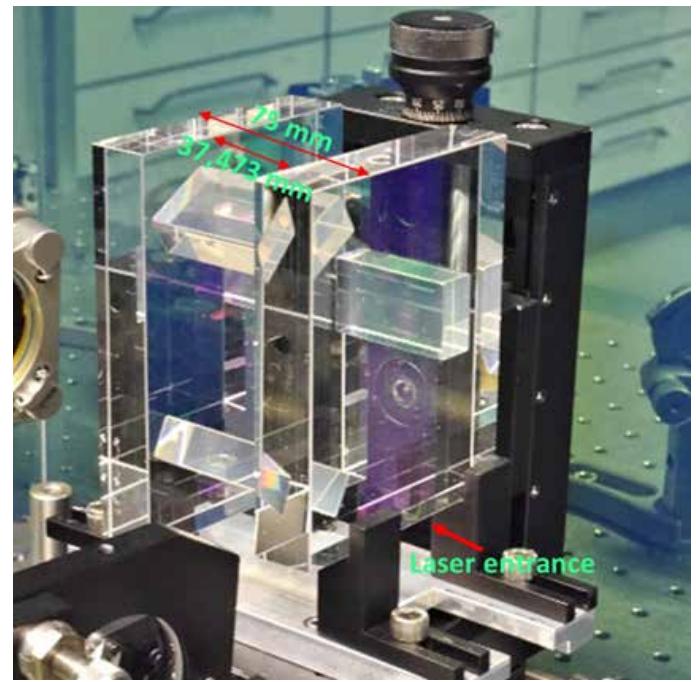


Photo of an air-spaced VIPA etalon with the laser entrance in the lower part of the coupling window

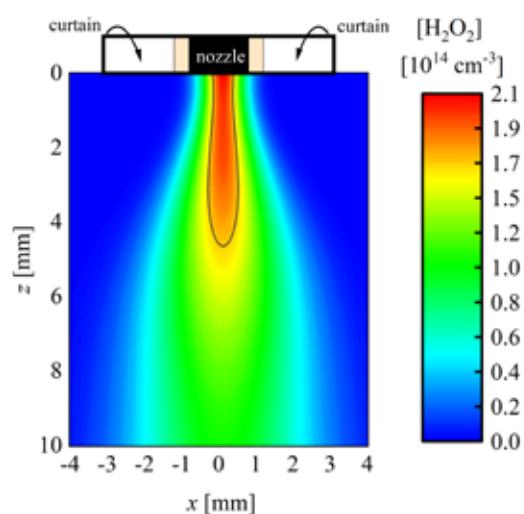
Application Laboratory Plasma Diagnostics

For the investigations, specially equipped laboratories are available for diagnostics on chemical plasma processes simulated in a practical manner with state-of-the-art measuring equipment, in particular laser-based plasma diagnostics. The following methods are used for the quantitative determination of important parameters, such as the species densities and their temperatures as well as the energy distribution of charged particles, and for the characterization of relevant chemical reaction paths:

- Laser-induced fluorescence and absorption spectroscopy with coherent light sources in the spectral ranges:
 - UV-VIS: pulsed dye-laser
 - Mid-IR: diode laser, quantum cascade laser, interband cascade laser, lead-salt diode laser, frequency comb laser system
 - THz: quantum cascade laser, Terahertz time-domain Spectroscopy
- Cavity-enhanced spectroscopy
 - CRDS - Cavity Ring-down Spectroscopy
 - CEAS - Cavity-Enhanced Absorption Spectroscopy
 - OF-CEAS - Optical Feedback Cavity-Enhanced Absorption Spectroscopy
- Absorptions spectroscopy with incoherent light sources (FTIR-Spektroskopie from VIS to mid-IR)
- Optical emission spectroscopy (UV-VIS: Grating spectrograph with CCD- und iCCD-Kameras)
- Probe diagnostic (Langmuir probe also for time-resolved measurements)
- Mass spectrometry (Quadrupole up to 200 amu)
- Synchronised electrical and optical sub-ns diagnostics

The diagnostic methods are also suitable for mobile use and can therefore be applied for external measurements directly at the customer's premises.

In 2019, the first application laboratory for plasma diagnostics with a focus on atmospheric pressure plasma sources was established at the INP. In this laboratory, various diagnostics of the institute are concentrated in one place in order to provide a central contact point for the characterization of atmospheric pressure plasmas. Here, important parameters such as atomic and molecular species densities in different types of plasma sources are quantified.



Contour plot of the H_2O_2 number density in the effluent of the kINPen-sci

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Overview

The investigation of thermal plasmas and their applications is the main field of activity of the research programme "Thermal Plasma Technologies".

Thermal plasmas play a crucial role in process engineering in particular, as well as in protection systems and switching devices in electrical engineering. The research programme focuses on the diagnostics and physical characterization of electric arcs in order to develop alternative solutions and for monitoring and process optimization tasks. The areas of application involve thermal processes in metalworking (arc welding, plasma cutting) as well as vacuum switchgear, applications in chemical process engineering and for the electrification of thermal processes.

In electrical power engineering, thermal plasmas occur in the form of so-called switching arcs, which are ignited by switching devices in electric grids. The characterization of this predominantly transient arc discharge in interaction with the electrodes and adjacent components (housing walls, etc.) in low- and high-voltage systems is the focus of the research programme.

The discharge and arcing phenomena that occur because of insulation faults, disturbing the normal operation of electrical systems and devices, and that lead to a reduction in service life and functionality are also investigated.

Due to the complex arc character and the dynamic interaction with its surroundings, unified modelling of thermal plasmas still represents a scientific challenge today. Especially for the near arc regions, the involved materials and the surrounding gases often determine the range and application possibilities of the model results. The constant development of new types of components and electrically powered devices, changing fields of application and increasingly environmental requirements call for continuous research into both the arc itself and the technological adaptation to the respective boundary conditions. The scientific approach combines diverse experimental diagnostic methods with mathematical modelling and simulation. This enables the determination of space- and time-dependent plasma parameters such as temperature, composition and gas dynamics.

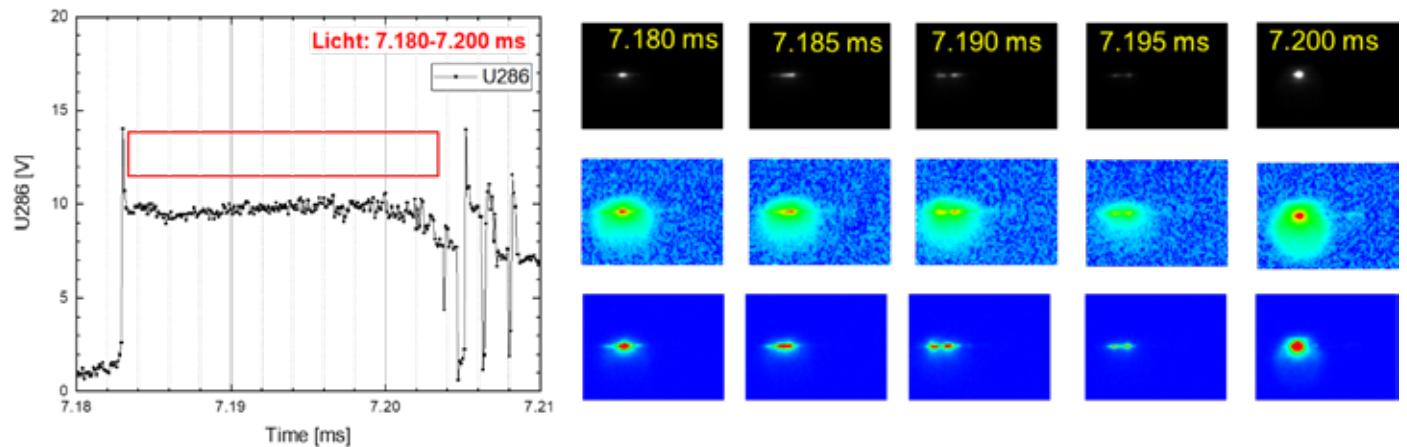
The INP has a unique selling point in the field of optical plasma diagnostics in particular. The research programme uses optical emission and absorption spectroscopy as well as their combination with high-speed imaging and high-speed two-colour pyrometry. A significant expansion of expertise is achieved through the adaption of absorption spectroscopic methods to analyses the areas adjacent to the arc and after current zero in switching devices.

For modelling and simulation, both classic magneto hydrodynamic models (Navier-Stokes and electromagnetic equations) and, increasingly, non-equilibrium models are used. The latter avoid the a-priori assumption of local thermodynamic equilibrium. This makes it possible to achieve significantly higher accuracy in the description of the occurring processes in the near electrode regions and plasma-wall interaction as well. In addition, the research work on radiation transport and material data for plasmas is the focus of interest of the research programme.



Left: Transient voltage generator (TRV) up to 45 kV @ 1 kHz. Right: High current generator (Weil-Dobke synthetic circuit type) up to 80 kA @ 50 Hz

Joint project "AutoHybridS"



Compilation of voltage waveform (left) and high speed images (video sequence) of a hybrid switching process between Ag electrodes in a DC 400 V circuit.

The joint project "Autonomously controlled hybrid switch with efficient dielectric recovery detection - AutoHybrids" was funded by the BMWK between Dec. 2020 and Nov. 2023 and brought together partners from industry and science

The joint project "AutoHybrids" focused on the optimization of hybrid switchgear technology for electric power grids with rated voltages of up to 850 V DC. The focus was to the characterization of the physical processes by hybrid switching in order to draw conclusions for an efficient, extremely fast-tripping switching technology and safe power interruption.

The aim is to develop a fast DC hybrid circuit-breaker for use in industrial and on-board grids for the system integration of renewable energies and for energy recuperation from electric drives.

Hybrid switching devices allow to combine the advantages of mechanical switching (low conduction losses, galvanic isolation) and those of power semiconductors (fast switching) in one device. This approach is being pursued for the new hybrid switch, which is being developed. Through the combination of mechanical switching contacts with power electronics connected in parallel, it shall be possible to safely extinguish the switching arc within μ s. To ensure that the current is safely interrupted and avoid re-ignition, it is however necessary that the contact gap has dielectric recovered, before the semiconductors switch-off the current.

As part of the project, a model hybrid-switch was developed and tested at the INP. Comprehensive high-speed imaging technology and spectroscopic measurements with high temporal and spatial resolution made it possible to detect and characterize the plasma between the electrodes during the arc

and post-arc phases. By using suitable filters, the temporal behaviour between species from the ambient gas (O_2) and the corresponding electrode material (Ag, Cu) during and after the arc phase could be characterized.

Based on the experiments and mathematical modelling of the electrode gap, both the temperature of the plasma over time and the dielectric behaviour of the ionized gap, particularly after zero current, were determined. Further measurements using optical absorption spectroscopy made it possible to determine the species density and its contribution to the temporal dielectric recovery of the electrode gap. Numerical simulation using a 1D-t Fluid-Poisson model developed for this purpose made it possible to take various parameter combinations into account. It was found that despite the high pressure and high charge carrier densities, the plasma exhibits significant deviations from thermal equilibrium, so that a considerable temperature increase of the gas only takes place at currents above 200 A. By varying the current, a current-resistance characteristic was obtained, which is used by the project partner in electrical models of the entire system.

The aim of the INP part within the project was to develop the decisive specifications that enable the detection of dielectric recovery. Both spectroscopic and plasma-physical analyses on a hybrid-switching model and the derivation of a mathematical model were used for this purpose. For the economic design of the semiconductor, the results provide starting points for determining the necessary turn-on times of the hybrid electronics so that reliable dielectric recovery of the contact gap can be guaranteed when the transient recovery voltage takes place.

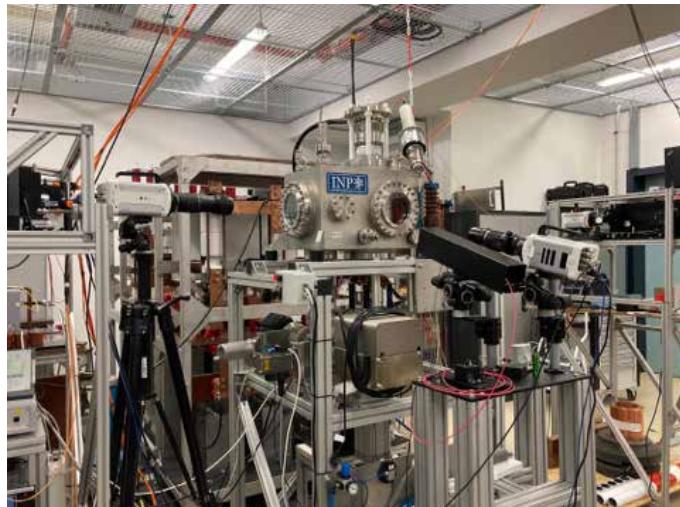
Core-funded project „Electric Arcs“

A significant improvement in the switching capacity and reliability of arc-based switching devices requires detailed knowledge of the physical properties and dynamics of the resulting arc plasma. The near plasma regions at the electrodes and housing walls deserve particular attention here. The focus of the basic-funded project is the interaction between plasma and the surrounding medium (air, gas, vacuum), which is being investigated using high-resolution optical diagnostics in combination with numerical modelling.

Extensive work is being carried out in the frame of this project. In particular, the analysis of arc spots at the anode under vacuum. By using the experimental set-ups and high-current and high-voltage generators developed for this purpose, new insights were gained into electrode phenomena when switching off higher current amplitudes i.e. high current densities during the reporting period.

Experimental efforts are currently being carried out to characterize magnetically induced contraction phenomena of the high-current arc and their interaction with the electrode areas. The oscillating plasma jets that accompany the ap-

pearance of anode spot type 2 have also been observed with different electrode materials. Further investigations using optical video spectroscopy are currently underway and should provide further information about this phenomenon by using new high-speed cameras with higher dynamic detection ranges. The aim here is to strengthen the experimental results by means of mathematical simulation.



Vacuum model switch of TPT including extensive optical measurement technology in the arcing laboratory to investigate the high current phenomena in the high voltage vacuum switch.

Application-oriented outlook

The "Thermal Plasma Technologies" research programme investigates the behaviour and properties of the electric arc and its interaction with adjacent areas (electrodes, surrounding walls) and ambient gases or metal vapour gas during vacuum switching processes.

The focus is on gaining knowledge of the physical phenomena and using it to adapt, optimise and develop new process variants, as well as to increase performance, improve efficiency and provide plasma-based alternatives to conventional thermal processes.

The field of research covers the electrical sector, various industrial process and production technologies, and, in the future, the safe disposal of problematic waste materials and the minimisation of the environmental impact of conventional products and production technologies.

The research programme is strongly user-oriented. In cooperation with industrial users, alternative solutions are developed for process control and continuous improvement of process stability, cost savings and optimal use of resources. The application and development of optical diagnostic techniques, such as high-speed kinematography, absorption and emission spectroscopy, pyrometry and laser-induced plasma spectroscopy, enable us not only to understand the plasma and its interactions, but also to derive sensor concepts that are easy to use and integrate. Due to the urgent need to reduce the CO₂ footprint of industrial processes and to store electrical energy from volatile renewable sources, alternative concepts for the targeted use of thermal plasmas in chemical process engineering or for the electrification of thermal processes and their integration into optimised energy cycles move into the focus of the research programme.

Research in electrical engineering, and in particular switch-gear technology from low to high voltage, includes the simulation of real processes using experimental set-ups and model switches with optical access. This enables the use of spectroscopic diagnostics, which is essential for the experimental determination of the physical properties of the arc. The research programme is unique in this area and currently investigates the radiation properties of the arc, electrode erosion and the reconsolidation behaviour of switching paths.

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Plasma Radiation Techniques

The department's expertise comprises the experimental analysis of technological plasmas in various applications of electrical power engineering (high-current, high-voltage and switchgear technology) and process engineering (welding technology, thermal conditioning of metallic surfaces). Electrical and optical diagnostic methods are used for quantitative analysis, with a focus on emission spectroscopy. Research currently focusses on investigations of switching arcs in arresters and contactors, vacuum arcs in circuit breakers, arcs in material conversion processes as well as micro arcs and spark discharges.

The further development of methods of high-speed cinematography coupled with optical emission and absorption spectroscopy serves to optimise the physical properties of the plasmas investigated in practical model arrangements and laboratory experiments. The focus is put on increase of sensitivity and spatial resolution of optical methods, extension of their applicability to cold plasma regions and surfaces, characterisation of spatially asymmetrical plasmas with high dynamics, robustness against interference in real applications and flexible and mobile use. In addition to quantitative analysis of local arc properties, the determination of surface temperatures and other properties, such as those of electrodes, in various arc applications is of interest.

Based on expertise in diagnostics, the department develops application-specific, non-invasive sensor and control systems. In addition to state-of-the-art diagnostic systems, the department has the appropriate welding technology, high-current and high-voltage technology and vacuum technology.



A view at the arc laboratory: synthetic test circuit (right in the picture, developed in-house by the INP), vacuum chamber with pump system and drive (left in the picture).

Technological equipment

Arc research laboratory

- Synthetic test circuit for switchgear with maximum current up to 80 kA and transient recovery voltage up to 42 kV
- Pulse current generator with variable current form (AC with variable frequency 16-1000Hz, pulsed DC, lightning pulse)
- Vacuum chamber for investigations on high-current vacuum arcs
- Equipment for electrical and optical diagnostics

Arc welding laboratory

- Test stands with fixed torch holder and flexible movement of test workpieces under the torch, including gas supply, smoke outlet, radiation protection
- Power sources from various manufacturers as well as a free programmable power source
- 15 kW water vapour torch
- Equipment for electrical and optical diagnostics

High-voltage laboratory

- HV generator for AC voltages up to 100 kV, DC voltages up to 130 kV, pulse voltages up to 135 kV
- Partial discharge diagnostics according to IEC 60270, frequency response analysis, acoustic sensors, UHF sensors, measurement of dielectric response, resistance meters

Continuous current laboratory (at Rostock University)

- Continuous current test stand (max. 3000 A)
- Climatic chamber for cooling and heating cycles (-70 - +180 °C) and heating ovens (+250 °C)
- Thermographic camera
- Thermal probes
- Resistance measuring devices ($n\Omega$ to $\mu\Omega$)

Low-voltage switches and spark diagnostics laboratories

- Test stands with suitable power generators to simulate realistic operation
- Measuring stations for optical investigations on small-scale and low-light objects (micro arcs, partial discharges, lightning current discharges)
- Optical calibration sources
- Double-pulse LIBS system for determination of material compositions
- Equipment for optical measurements

The following equipment for optical measurements is available to all laboratories:

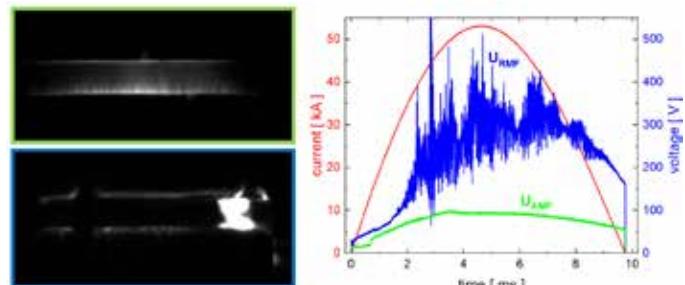
- Mobile and stationary measuring stations for imaging optical emission spectroscopy and optical absorption spectroscopy
- High-speed and ultra-high-speed cameras
- Diagnostic systems for thermography and pyrometry

The department has an X-ray system for computer tomography for non-destructive diagnostics of electrodes or material samples.

Future research focus

- Expansion of expertise in the field of plasma pyrolysis and thermal gas conversion
- Consolidation of expertise in the areas of environmentally compatible switching media, autonomous power grids and electromobility
- Further development of quantitative diagnostics in the field of high and ultra-high pressure arcs

- Adaptation of existing optical measurement methods for temperatures below the melting point for studies of cooling dynamics of metallic surfaces and analysis of the energy balance
- Construction and commissioning of an energy laboratory at the Centre for Life Science for research of various thermal plasma applications
- Conducting studies on material conversion in plasma-assisted high-temperature conversion processes
- Measurements of species densities and temperatures in thermal non-equilibrium plasmas by spectroscopic methods

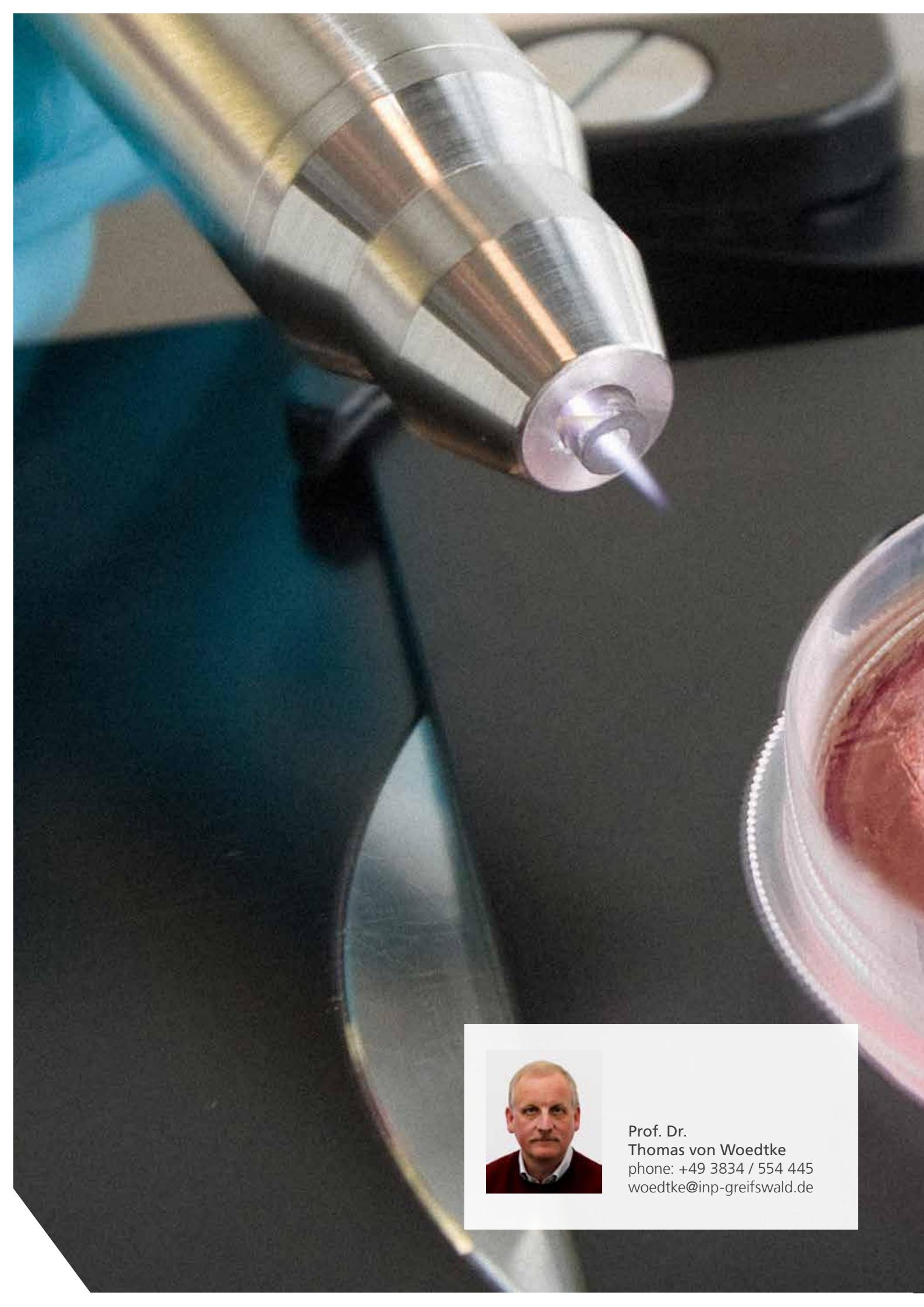


Left: High speed images of a vacuum arc at the instant of current maximum in the case of AMF (top) and RMF (bottom) contact groups.
 Right: Current- and voltage courses for 50 kA vacuum arcs with AMF and RMF contact groups.

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RESEARCH DIVISION

HEALTH & HYGIENE

Overview

The Health & Hygiene research division focuses on the use of atmospheric pressure plasma sources in medicine and for the modification of surfaces. The focus in plasma medicine is on application-oriented fundamental research into the interactions of physical plasmas with living cells and tissues. Together with clinical partners, we ensure the transfer to medical applications. Areas of application include wound healing, infection protection and cancer treatment. We use plasma surface modification to create customized properties for metal, ceramic, glass and plastic surfaces. Areas of application include the life science sector, biosensor technology and a wide range of technical applications. We have many years of experience in the development of plasma-assisted processes for the refinement of product surfaces. The spectrum ranges from structured material deposition and the targeted adjustment of interface properties to the production of functional layers.

Research Programmes of the Division:

Plasma Surface Modification

Plasma Medicine

Branch Office Kompetenzzentrum Diabetes Karlsburg

Overview

For many applications, in particular in the field of life sciences, targeted surface modification of products is necessary in order to create specific properties. The plasma-based processes used in the research programme Plasma Surface Modification (PSM) are well suited for this purpose due to their environmentally friendly and substrate-friendly properties. Plasma-assisted surface processes are versatile, user-friendly and enable the customised modification of a variety of differently shaped surfaces and a wide range of substrate materials.

Polymer layers generated via plasma-surface modification are stable, resistant and sterilisable. The targeted plasma-assisted generation of application-oriented chemical functionalities makes it possible to equip a broad range of products with new properties that cannot be generated in any other way. The processes used in the research programme to produce antimicrobial, biocompatible or biomimetic surfaces as well as the methods used for plasma electrolytic fine cleaning and fine deburring of medical devices open up new perspectives for the application of plasma processes in the field of life sciences.

Surfaces are functionalized using low-temperature plasmas in order to improve the interfacial compatibility of biomaterials and to initiate specific reactions of biological systems in contact with the surface. In addition, new, specific properties for biomedical and biotechnological applications are generated on the substrates almost independently of the

substrate geometry and the material by means of plasma coatings. As process times and costs as well as the simple integration of plasma processes into existing production lines are often of great importance for industrial applications, the research programme is works together with the Plasma Surface Technology department to investigate plasma processes at low pressure for maximum purity and at atmospheric pressure for short process times.

Another focus of the research programme is the development of processes for the production of chemically microstructured surfaces and functional layers for biosensor platforms for the immobilisation of various biomarkers or proteins for diagnostics. The control of the wetting properties of substrates is particularly important here, as plasma-based processes can be used to tailor the wettability of surfaces or generate certain chemical functions on the surface. This work is carried out in close cooperation with the Biosensing Surfaces junior research group.

Application-oriented outlook

Fields of application

Antimicrobial surfaces:

Antimicrobial surfaces are mainly used for passive infection prevention. Implants in particular, but also forceps, scalpels and other medical devices that come into direct contact with the patient or medical staff, benefit from this type of functionality. Various plasma-based processes are used to reduce or completely prevent the colonisation of surfaces with pathogenic bacteria.

This includes, for example, photocatalytically active layers based on titanium dioxide, which have antibacterial and self-cleaning properties when exposed to light, or antimicrobial layers whose effect is based on metallic components such as copper or silver. In order to produce an antimicrobial effect that is as long-lasting as possible, the metallic active ingredients can also be embedded in the original substrate material. This makes it possible to specifically adjust the release behaviour of the antimicrobial additives.

Cell-adherent surfaces:

Plasma processes are also suitable for equipping surfaces with reactive chemical groups such as amino and carboxyl groups. This can significantly improve the colonisation of surfaces by cells and, in particular, cell density, cell distribution, adhesion, proliferation and differentiation. In addition, the binding of biomolecules using different immobilisation strategies, such as the covalent coupling of linkers and spacers, is made possible.

Anti-adhesive surfaces:

Anti-adhesive surface properties are advantageous for transient implants such as fixators or temporary screw connections. This can be achieved by means of anti-adhesive plasma coatings. Substrates coated in this way are easier to clean, as dirt and oils/greases as well as organic material have difficulty adhering to them. With the plasma surface modifications used in the research programme, such surfaces can be created quickly, cost-effectively, environmentally friendly and flour-free.

Plasma electrolytic fine smoothing and fine deburring:

Plasma electrolytic polishing (PEP) is used in the research programme Plasma Surface Modification, in particular for fine smoothing and fine deburring of implants. Compared to other cleaning and polishing processes, PEP offers both economic and ecological advantages, as the process is comparatively fast, simplifies the process chain and reduces the costs for post-treatment and disposal of hazardous chemicals when compared with conventional electrochemical process.

Atmospheric pressure plasma spraying:

Atmospheric pressure plasma spraying is used in the research programme to deposit functional layers that have applications in electromobility, e.g., in electric vehicle heaters, but also in the life sciences, such as improving the ingrowth behaviour of implants. In the PRISMA project (ERDF), the plasma properties were characterised and the layer growth was visualised. The experiments were supplemented by simulations with the aim of improving process control.



Plasma electrolytic polishing in use as fine cleaning and deburring for medical devices

Core-funded project: Development of the Plasma Electrolytic Polishing Process for Complexly Shaped Stainless Steel Parts

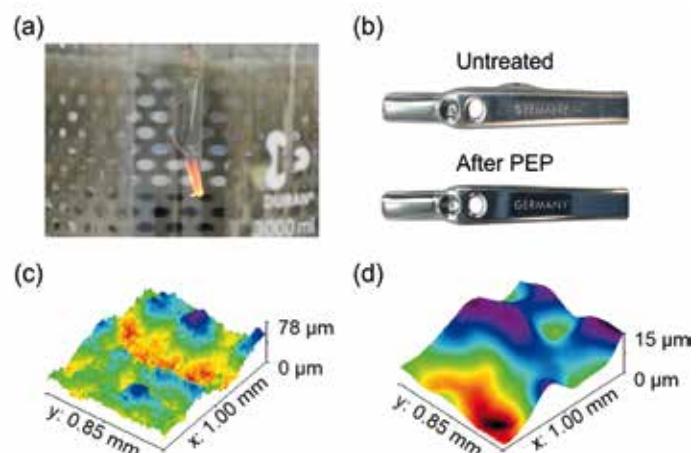
In recent years, rapid technological advancements have led to an increased demand for manufacturing objects with more complex shapes while maintaining high surface quality standards. This development has made the surface finishing of intricately shaped workpieces challenging with conventional methods such as mechanical polishing. Furthermore, environmental concerns associated with existing polishing methods have added to the complexity.

Plasma electrolytic polishing (PEP) has emerged as a compelling solution due to its ability to uniformly smooth surfaces across entire workpieces, while also reducing the environmental concerns typically associated with other electrochemical polishing methods. As illustrated in Figure (a), during the PEP process, a gas layer envelops the workpiece, accompanied by plasma, leading to surface modifications. To effectively implement the PEP process for the desired surface outcome, optimal process parameters have to be meticulously determined and validated through comprehensive surface analytics.

Therefore, the primary aim of our studies is to elucidate the influence of the PEP process on the surface of intricately shaped stainless steel workpieces. As part of the project, the optimum process parameters were determined. As depicted in Figure (b), after the PEP process using a 4 wt.% (NH₄)-2SO₄ electrolyte at 220 V, the stainless steel part acquired a glossy appearance due to the reduction of surface roughness resulting from material dissolution and subsequent surface smoothing. Furthermore, it was revealed that after the PEP process, the surface was cleansed, reducing aliphatic carbon and removing the native oxide layer. This process also allows for selective elemental control, and the material dissolution rate can be precisely controlled by adjusting PEP process parameters such as voltage, time, and electrolyte properties. Another aspect of these investigations emphasizes the direct integration of the PEP process with complexly shaped, 3D-printed metal components. The inherent roughness of the native surfaces of such 3D-printed parts often restricts their practical use, necessitating post-processing to enhance their surface quality. To illustrate the practical viability of PEP as a post-processing technique, optimal conditions for the PEP process were established, incorporating the implementation of a workpiece rotation sequence.

After the PEP treatment, the 3D-printed metallic components exhibited uniformly smooth surfaces, as demonstrated in the 3D surface topologies shown in Figures (c) and (d). The primary area targeted for practical application was a monomer mist chamber, used for plasma-polymerized thin film fabrication. Through the PEP process, such films can be fabricated now up to 10 times more efficiently, compared to those from an untreated chamber, within the same misting period, ensuring in addition high reproducibility.

Hence, this study highlights the influence of PEP on metallic surfaces and confirms its practical applicability, in particular, for stainless steel. It is proposed that PEP offers a promising approach for the post-processing of complex-shaped 3D-printed components to enhance their surface quality in an ecological manner.



Third-party funded project: PlasmaConstant - Coating complex components using atmospheric pressure plasma nozzles

The homogeneous treatment of surfaces with an atmospheric-plasma is a technically complex process, in particular on three-dimensional edges and in areas where the trajectories of the plasma source used overlap. A suitable process window is usually worked out through trial and error and existing experience. As this greatly extends the development times of the processes and long-term effects of the locally differing intensities during activation often cannot be fully taken into account, there is a great need for research here. A better understanding of the intensity differences in treatment caused by the flows in atmospheric plasmas is therefore of great interest to industry - also for optimising and making processes more effective.

As part of the PlasmaConstant project, two focal points were therefore pursued to gain a deeper understanding: firstly, the approach of simulating gas flows and plasma densities, and secondly, the visualisation of gas flows from plasma nozzles on sample geometries using Schlieren diagnostics in combination with a high-speed camera, which was carried out together with the Fraunhofer Institute for Manufacturing Technology and Applied Materials Research (IFAM) in Bremen.

Both approaches were analysed in detail for two compact, commercially available atmospheric pressure plasma sources that differ in the type of plasma used. These two approaches were then complemented by a large number of practical investigations for verification.

In addition to visualising the gas flows, the aim of the work is also to understand the gas flow on 3D geometries for the subsequent optimisation of the treatment of possible geometries. In particular, the process control is at the centre of this and was tested using examples. This comparison between the real experiment and virtual and optical visualisation also served to verify the derived findings for the optimisation of process control on simplified 3D structures. In addition, the experimental findings were directly incorporated into the flow and plasma propagation simulations.

The results were then used to derive measures for a homogeneous treatment of the surfaces. The review was carried out using model components to derive further recommendations for action with regard to subsequent process control. In addition to this review, a catalogue of questions was developed for later consideration in process development in industry and designed in the form of a decision tree for essential influencing factors. The aim here was to provide the most generally understandable questions for deriving influencing factors in process development.

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Plasma Surface Technology

The Plasma Surface Technology department develops and optimises plasma-based processes for modifying surfaces that are used in various industries, including the high-tech sector, automotive engineering, the aerospace industry, microelectronics, fusion research, tool coating, textile industry and plastics processing. Innovative processes are also developed for applications in the life science sector, for example in biomedical engineering for implants, medical instruments, biosensors or in the food industry.

Plasma processes in surface technology cover the spectrum from structured material removal, such as etching or fine cleaning, to the adjustment of interface properties, e.g. to control bondability or printability, to the production of thin functional layers with applications for protection against corrosion, heat or mechanical abrasion. Process-related advantages of plasma processes include, for example, a low thermal load on the components and comparatively improved environmental friendliness, particularly in light of current regulations on authorised materials.

The expertise includes:

Interface engineering

- Modification of metal, ceramic, glass and plastic surfaces
- Antimicrobial surfaces
- Setting the adhesion for material composites
- Hydrophilic/hydrophobic surfaces
- Biocompatible surfaces
- Cell-adhesive/cell-anti-adhesive surfaces
- Textile treatment

Process development for the deposition of thin films

- Hard materials
- Wear protection
- Corrosion and oxidation protection
- Optical coatings
- Scratch-resistant surfaces
- Photocatalytically active surfaces
- Decorative layers, surface finish
- Plasma fine cleaning
- Plasma-based polishing, deburring and cleaning of metals
- Polishing 3D-printed metal components

Technological equipment

Various plasma processes are used under low and atmospheric pressure conditions, which are constantly being further developed. Both laboratory and industrial-scale systems are available for this purpose, in some cases multi-chamber systems coupled to airlocks and quasi-in-situ surface analysis (XPS):

- Processes in DC, DC-pulsed, high-frequency and microwave plasmas
- Ion implantation (PIII and PIII&D)
- Magnetron sputtering
- High Power Impulse Magnetron Sputtering (HiPIMS)
- Plasma spraying
- Plasma electrolytic oxidation and polishing processes
- Plasma ion assisted deposition (PIAD)
- Plasma-enhanced chemical vapour deposition (PECVD)
- Surface modification using atmospheric pressure discharges (DBD, plasma jet)



Thermal atmospheric pressure plasma spray process for the production of functional layers. Shown here: Oxide layer on metallic implant

Surface analysis is one of the INP's areas of specialisation. The existing range of diagnostic procedures, the operating expertise and the methodology for analysing the measurement data are constantly being expanded and improved.

Analysis of topography and morphology

High-resolution scanning electron microscopy (HR-SEM)

- Transmission scanning electron microscopy (STEM)
- Atomic force microscopy (AFM)
- Profilometry
- White light interferometry
- Light microscopy with 3D function

Determination of the chemical composition, binding and structure

High-resolution X-ray photoelectron Spectroscopy (XPS)

X-ray diffraction (XRD)

FTIR spectroscopy

Determination of wear resistance

- Abrasion test
- Calotte grinding process

Investigation of mechanical properties

- Microindenter
- Nanoindenter
- Measurement of the adhesive strength of bonds

Determination of contact angle and surface energy

- Contact angle measuring devices (static and dynamic)

Determination of the optical properties

- UV-Vis spectrophotometry
- Optical ellipsometry

The following topics are the subject of current developments in the application of plasma surface technology processes at the INP:

- Surface finish of 3D-printed workpieces
- Plasma smoothing of conductive surfaces
- Development of modern plasma processes for coating deposition under normal pressure
- High rate separation process under normal pressure (Plasmaspraying)
- Use of plasma-based methods for process control and regulation
- Use of in situ surface analysis



Plasma-electrolytic polishing: Comparison of a polished (left) and an unpolished component (right)

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Biosensing Surfaces

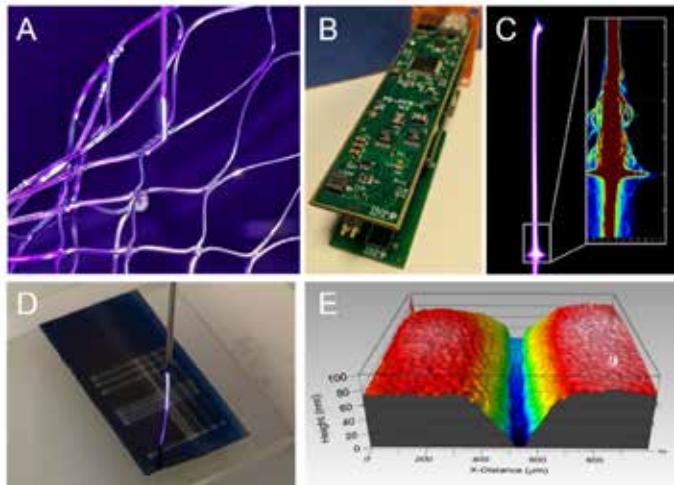
In an interdisciplinary research environment at the interface of plasma technology, systems engineering, polymer chemistry and materials science, the junior research group Biosensing Surfaces (BSO) continues to work on the development and characterization of novel functional coatings and atmospheric-pressure plasma processes for surface engineering. The main focus is on applications in medicine, biotechnology and, more recently, in microfabrication.

IN particular for biosensor and microfluidic applications, the control of physical, chemical, and biological interface properties is essential to ensure the best possible performance in interaction with the biological environment. Moreover, the fabrication of micro- and nano-structures on surfaces is also relevant for a variety of fields. Plasma-assisted surface modification processes are an innovative approach for the targeted generation of desired surface functionalities or for the realization of completely new surface characteristics through deposition and/or selective removal of thin layers.

Plasma Printing

Physically and chemically structured surfaces in the sub-millimeter to micrometer range are particularly valuable in biochips, electronics and photonics, among other fields. The consolidation and further development of INP's own plasma printing technology, known as Surface Atmospheric-Pressure Plasma Printing (SurfAP3®), has been carried out in the past two years. It is a state-of-the-art innovation with unprecedented resolution when it comes to maskless atmospheric-pressure plasma surface treatment. The flexible, direct-writing technology is now capable of creating structures with a linewidth resolution as fine as 40 μm (at least at 10x finer than comparable commercial technologies in the market). It allows nowadays not only for the deposition of thin films, but also for precise cleaning, activation, functionalization and layer removal across various materials (e.g., silicon wafers, glass, and polymers), which can be advantageous for different microfabrication workflows. In addition, the open nature of SurfAP3® facilitates experimentation with different precursors and integration with other technologies, such as additive manufacturing, laser patterning and microprinting, which is expected to be explored in the future with the cooperation of different academic and industrial partners.

SurfAP3® is currently in the process of reaching the technology readiness level (TRL) number 5 (validation in intended environment) and is expected to reach TRL 6 during 2024-2025. Furthermore, steps to transfer the technology to the market have been started in 2023, with the internal launch of INP's spin-off "MicroQuasar Technologies".

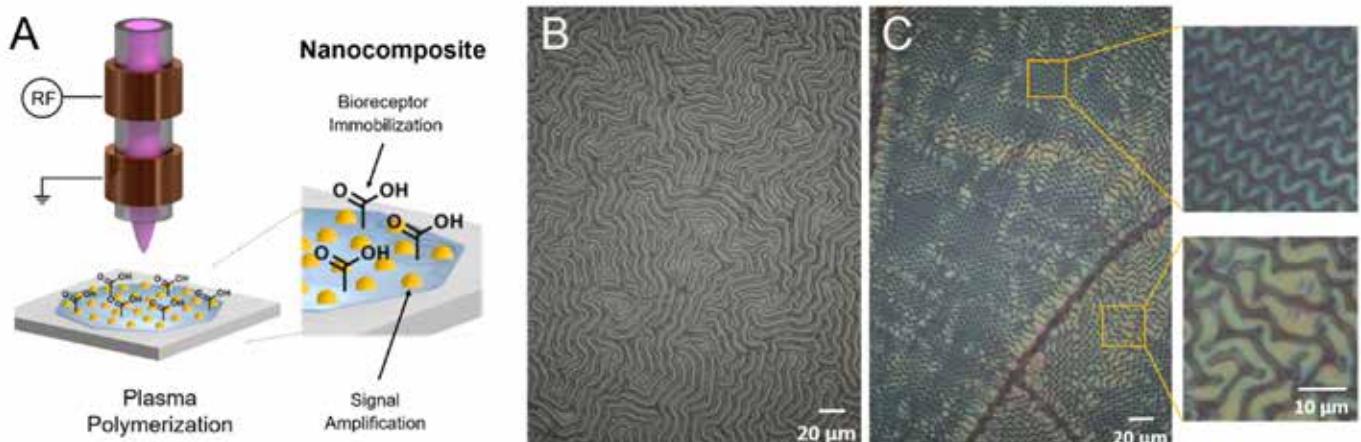


Plasma printing and related development processes in action. A) SurfAP3® precise treatment on a medical stent. B) Image of the electronics of the μ APPS developed during 2023. C) Picture of a plasma filament discharge generated with the μ APPS, with an insert of an image analyzed by the program BLITZ ("Bulk Loading and Interactive Time series Zonal analysis", developed by PQK), to understand the instabilities of the plasma source and their influence in the resulting micropatterns obtained with SurfAP3®. D) and E) Area-selective removal of a hydrophilic polymer thin film deposited on a silicon wafer (left), and white light interferometer analysis of a line feature (right).

Plasma source and plasma processes development for microfabrication

Part of the innovation with the plasma printing technology relies on the plasma source used. This novel and powerful micro atmospheric-pressure plasma source (μ APPS), has been developed, optimized and characterized in close cooperation with the research group Plasma Sources Concepts (PQK). The iteration and characterization of μ APPS (by means of electrical and advance imaging diagnostics) have been used to further optimize it, in order to prepare the device for transfer to the industry and the respective certified approvals. In this sense, functional improvements and development of new features are carried out by BSO by means of the methodologies of rapid-prototyping (additive manufacturing, systems engineering), design thinking and product management, expanding at the same time these competences of the research group.

In addition, growing competence in the development of plasma processes at atmospheric pressure, in particular for thin films and microfabrication applications, has been attained. Through systematic research, surface characterization expertise and formal design of experiments (DOE), we continue to investigate the process and products of maskless plasma printing as well as for the newest process developed of high aspect ratio area-selective removal of thin layers at micrometric scale.



A) Schematic representation of polymer-gold nanoparticle composite thin films for signal amplification in biosensors. B) and C) Differently arranged polymer structures deposited on Si wafers generated by plasma-induced self-assembly depending on the plasma exposure time and direction, and the precursors used.

Functional Films

In biosensors, achieving the selective detection of the analyte within a sample requires surface modification of their biological recognition film. Thus, the surface chemistry of the recognition structure plays a pivotal role, preventing unspecific interactions and ensuring targeted coupling of the analyte binding partner on the sensor surface. For accurate measurements in real samples, it is imperative that the functionalized surface exhibits adequate immobilization density and high binding activity, to ensure the capability to detect even low concentrations of the analyte. One focus of BSO is therefore the generation of thin plasma-polymerized (pp) layers containing functional groups that allow the efficient coupling of the analyte binding partner. Building on the foundation of our previous investigations of carboxyl-rich films that proved unique functionality and excellent adhesion to the substrates, we continued to investigate on new precursors to expand the repertoire of surface functionalities to make further immobilization strategies for a range of biomolecules accessible. To this end, new precursors are tested which, through exposure to atmospheric pressure plasmas, form a functional thin film suitable for the immobilization of the targeted biomolecule via electrostatic interactions and routinely applied covalent coupling chemistries. This approach is complemented by single-step modification procedures of the deposited thin films using non-hazardous bifunctional small molecule linkers, which enable the modular attachment of chemical moieties for the capture of biomolecules.

Moreover, in order to allow for signal amplification capabilities for our acrylate-based pp films, the addition of different nanoparticles (gold, carbon nanotubes and graphene) to our standard atmospheric-pressure plasma liquid deposition (APPLD) process was tested. Here, the production of polymer-gold nanoparticle composite thin films with a simple and cost-effective process was proved. Furthermore, electro-

chemical characterization revealed a positive signal amplification effect in the range of one order of magnitude, compared to pp films without nanoparticles, thus showing once again the potential of pp films as effective immobilization matrixes for biosensing applications.

Considering our previous results on the synthesis of pp thin hydrogels as starting point, new investigations on self-assembly phenomena of oligo- and polyethylene glycol macromonomers exposed to atmospheric-pressure plasma were initiated. The aim is to reveal the impact of the precursor architecture, solvents, additives as well as process parameters, to ultimately control the shape and directionality of the self-assembled structures, which could be used for different photonics applications.

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Overview

The research programme Plasma Medicine combines specialist expertise from life sciences with plasma physics and plasma technology skills available at the INP. This includes basic research on the interaction of cold atmospheric pressure plasma with living cells and tissues as well as application-oriented research on potential areas of application of physical plasma in the context of medical therapy concepts. The following three topic areas were the focus of the research work:

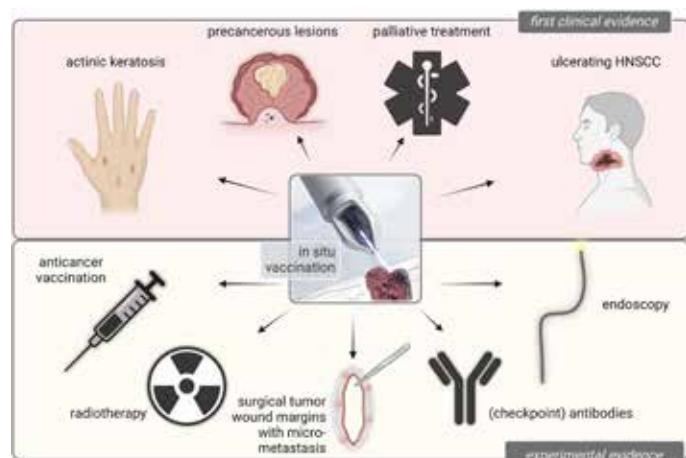
- Clarification of the biochemical and molecular mechanisms of biological plasma effects with particular attention to redox-based processes
- Scientific and conceptional support for clinical research and therapeutic use of cold atmospheric pressure plasma sources
- Investigating the efficacy of experimental plasma sources for various biomedical applications

A wide range of microbiological, chemical-analytical as well as cell and molecular biological techniques are available in modern laboratories for this research work, which is combined with plasma physics and engineering expertise established at the INP for many years in an interdisciplinary research structure. The research programme Plasma Medicine closely works with the Karlsburg Diabetes Competence Centre (Kompetenzzentrum Diabetes Karlsburg, KDK) and the cross-sectional departments of Plasma Life Science and Plasma Sources of INP.

In 2022 and 2023, in addition to further contributions to the elucidation of the molecular mechanisms of plasma-supported wound healing, significant knowledge advances were made in the area of plasma-mediated inactivation of cancer cells. This area, which was also intensively investigated internationally during the reporting period, is intended to lead to future therapy concepts for cancer treatment. Extensive research into the modification of biomolecules by means

of plasma treatment contributed to a better understanding of the plasma-induced modulation of cellular signaling cascades and the resulting biological effects. Moreover, the finding that such molecular changes can also have immunogenic effects opens the way to innovative concepts for therapeutic vaccination in the context of cancer treatment. Results on the variation of biological plasma effects by modifying the composition of the plasma working gases and the plasma-target distance contribute to optimizing the therapeutic use of cold atmospheric pressure plasma sources.

The KDK, located at the Karlsburg Clinic, has further consolidated its activities as a branch of the INP for application-oriented, clinic-related plasma medical research. In close collaboration with the research programme Plasma Medicine, the focus here is on the characterization of plasma sources within the framework of research projects with industrial partners, supporting the development of medical products and biotechnological processes, especially for diabetes therapy, within the framework of joint projects, as well as clinical research on plasma-assisted wound healing that accompanies standard therapy.



Potentials of using plasma technology in cancer therapy (source: Redox Biology; <https://doi.org/10.1016/j.redox.2023.102798>)

Application-oriented outlook

The argon-operated cold atmospheric pressure plasma jet kINPen, designed at the INP, continues to form an essential basis for application-oriented research expertise in the field of medical plasma devices. The many years of experience with this plasma source have been used to design, develop, and characterise other plasma sources developed at INP or in collaboration with cooperation partners. Based on its many years of internationally visible research expertise, INP has become a recognized consultation and cooperation partner profiled in the field of plasma medicine for industry, research, and clinics. In the work on novel plasma sources and concepts, regulatory requirements for medical devices are taken into account right from the start in order to enable rapid transfer of results into prototypes (and later, by industry partners, into products) that can be used medically. INP is involved in national and international standardization activities, such as the further development of DIN SPEC 91315 and the international standard IEC 60601.

In February 2022, the Association of Scientific Medical Societies e.V. (AWMF) published the S2k guideline 007 - 107 "Rational therapeutic use of cold physical plasma", which particularly recommends the use of plasma in the treatment of chronic wounds. As part of the German National Centre for Plasma Medicine e.V. (NZPM), representatives of the INP played a key role in drafting this guideline. This guideline is an important milestone on the way to acceptance and use of plasma devices in medical practice.

DEVELOPMENT OF NEW APPLICATION AREAS

In 2022 and 2023, a major focus of research work was on exploiting the potential of plasma in the field of cancer treatment. Following a large number of experimental demonstrations of cancer cell killing by plasma with INP being a global leader in this field, the research programme Plasma Medicine addresses open questions important for the clinical implementation of cold atmospheric pressure plasmas in cancer therapy. For example, it needs to be clarified which effects sublethal plasma treatments have on cancer cells (Cancers; <https://doi.org/10.3390/cancers11091237>) or whether repeated plasma application can lead to the development of resistance in cancer cells (British Journal of Cancer; <https://doi.org/10.1038/s41416-023-02343-6>).

The long-awaited possibility of using cold atmospheric pressure plasmas in dentistry was further advanced as part of an industry-led project for the cleaning and functionalization of implant surfaces *in vivo* with INP participation. As part of this project, a clinical study has been carried out since 2022 that tests cold atmospheric pressure plasma in combination with mechanical water jet treatment for its suitability as an innovative concept for the treatment of peri-implantitis. Another field of application, particularly motivated by the COVID-19 pandemic, is the use of plasma-based methods for the anti-infective treatment of the respiratory tract, which has so far been investigated as part of a third-party-funded project.

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S2k-Leitlinie

Rationaler therapeutischer Einsatz von kaltem physikalischem Plasma

AWMF-Register-Nr.: 007 – 107

Schlagworte: Wundbehandlung, Kälteplasma

Zitation der Leitlinie
 Deutsche Gesellschaft für Mund-, Kiefer- und Gesichtschirurgie (DGMKG)
 Rationaler therapeutischer Einsatz von kaltem physikalischem Plasma
 Version 1.0 vom 23. Februar 2022
 Verfügbar unter: <https://www.awmf.org/leitlinien/detail/ll/053-054.html>
 Zugriff am (Datum)

Stand: 23/Feb/2022
 Gültig bis: 23/Feb/2025

Leitlinienkoordination: Prof. Dr. Dr. Hans-Robert Melemann

S2k-Leitlinie, AWMF-Register-Nr.: 007-107, Stand: 23. Februar 2022

Front cover page of the German S2k medical guideline on the rational use of cold physical plasma published in 2022.

Core-funded project Plasma & Zelle

The research work in the research programme Plasma Medicine was carried out mainly within the framework of the BMBF-funded Center for Innovation Competence (ZIK) "plasmatis – plasma plus cell". This work was supplemented and supported by the core-funded "Plasma & Cell" project. This enabled preliminary research to be carried out in order to lay the foundations for later project acquisitions and to examine new possible applications of cold atmospheric pressure plasma. In addition to the ZIK plasmatis, the core-funded project also offers the opportunity to supervise internships and qualification work for young scientists.

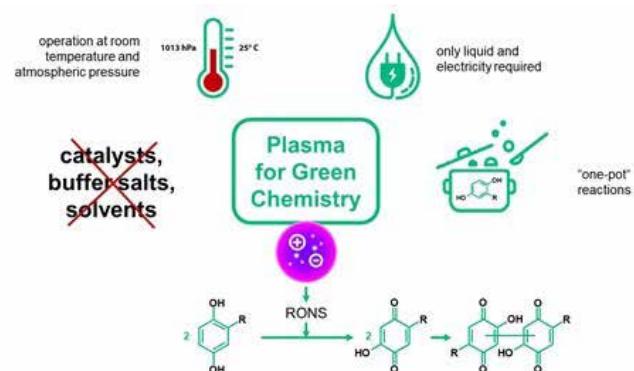
PLASMA EFFECTIVENESS IN WOUND TREATMENT – CLINICAL RESEARCH

Successful clinical studies carried out under controlled and reproducible conditions were the main basis for the acceptance and introduction of the use of cold atmospheric pressure plasma sources in general and the kINPen MED (neoplas tools GmbH Greifswald) in particular. Experience from clinical routine is particularly important for the further optimization of plasma use in therapeutic practice. In cooperation with the KDK, an observational study was carried out that scientifically monitored the use of the kINPen MED in the treatment of diabetic foot syndrome in the foot ambulance of the Karlsburg Clinic. Wound healing depending on treatment frequency, the influence of the wound microbiome by plasma treatment, and the identification of proteins in the wound secretion as potential markers for recording the progress of therapy were observation parameters. In addition to the results of the study, which have not yet been finally evaluated, the study methodology, in particular, is to be optimized so that such data can be collected better and more systematically in the future as part of routine medical treatment.

PLASMA APPLICATION FOR THE TARGETED SYNTHESIS OF CHEMICAL SUBSTANCES

The investigation of chemical changes of biomolecules in liquid phases has been an important element of basic research in plasma medicine to elucidate the biochemical mechanisms of action of cold atmospheric pressure plasma.

Based on it, research work on the plasma-assisted degradation of pollutants in wastewater has already been carried out at the INP in recent years. A new, innovative field of application is the use of plasma for the environmentally friendly synthesis of organic substances, which can be used, among other things, as pharmaceutical active ingredients. In close collaboration with the research programme Agriculture, Bio-economy, and Environment, initial work on plasma-assisted hydroxylation and dimerization of para-dihydroxylated aromatic compounds was carried out and published (Green Chemistry; <https://doi.org/10.1039/d2gc01624a>). Based on many years of work in basic research in the research programme Plasma Medicine, the area of plasma chemistry in liquids is to be further expanded as an innovative research field on the basis of this preliminary work, together with relevant activities in other research areas of the INP.



Plasma application in 'green chemistry' (source: Green Chemistry; <https://doi.org/10.1039/d2gc01624a>)

Third-party funded projects

CENTER FOR INNOVATION COMPETENCE (ZIK)

“PLASMATIS - PLASMA PLUS CELL”

The funding of the ZIK plasmatis by the BMBF with a total of four junior research groups, which has been implemented in two phases since 2009, was completed at the end of 2022. The personnel and technical expertise was built up was gradually consolidated in the “Plasma Redox Effects” research group at INP since 2021. In addition, the META-ZIK “PlasMark - Marker-free diagnostics of environmental plastic using innovative opto-physical methods” was funded by the BMBF in 2020-2022. A multidisciplinary consortium of physicists, biochemists, biologists, and pharmacists from the three centres ZIK plasmatis at INP, ZIK HIKE at Greifswald University, and ZIK innoFSPEC at the Leibniz Institute for Astrophysics in Potsdam (AIP) investigated the possibilities of label-free diagnostics of plastic particles in biological matrices. It intended to better address questions about the extent to which microplastic particles are one of the causes of neurodegenerative diseases, cardiovascular diseases, or even cancer.

PROJECT ONKOTHER-H

The project “ONKOTHER-H: Development platform for innovative oncological therapies using the most common human cancer – skin cancer” lead by the Rostock University Medical Centre was funded as part of the Excellence Initiative of the State of Mecklenburg-Western Pomerania in the framework of the European Social Funds (ESF). As part of this network,

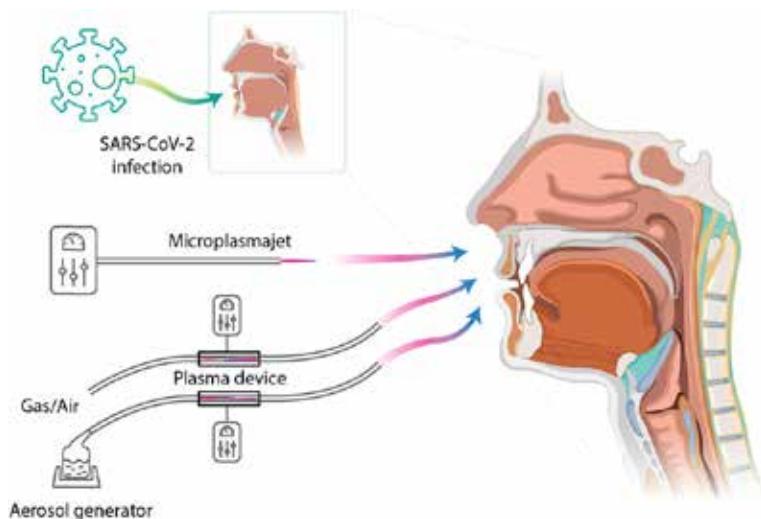
INP worked on the optimization of cold plasma applications, provided high-content screening data on plasma combined with novel small molecules in three-dimensional tumor spheroids, and performed in ovo experiments on the novel combination treatment efficacies (Journal of Advanced Research; <https://doi.org/10.1016/j.jare.2023.06.014>).

PROJECT DINPLAS

The DIN specification (DIN SPEC) 91315 “General requirements for medical plasma sources” was published already in 2014 under the leadership of the INP. In the project “DINPlas - Development of a DIN standard for testing the effectiveness and safety of atmospheric pressure plasma sources for medical applications” funded by the BMWi, the DIN SPEC 913145 is revised and reissued based on practical experience and new experimental work to optimize and adapt test methods for further practical application.

PPC – PLASMAPLUSCORONA

In the BMBF-funded project “PlasmaplusCorona - Plasma-based disinfection of the respiratory tract to reduce the SARS-CoV-2 viral load in vitro and in vivo”, a network consisting of the INP, the Borstel Research Centre (Leibniz Lung Centre), and the Leibniz Institute for Virology Hamburg investigates a novel plasma-based solution for local treatment of the respiratory tract (Plasma Processes and Polymers; <https://doi.org/10.1002/ppap.202200196>). The project also lays the conceptual and experimental foundation of plasma application for future pandemic threats and zoonoses.



Experimental approaches for the plasma-based local application in the respiratory tract (source: Plasma Processes and Polymers; <https://doi.org/10.1002/ppap.202200196>)

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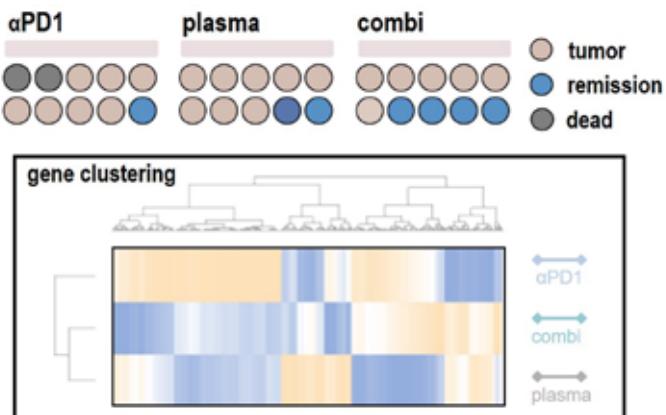
ZIK plasmatis Plasma-Redox-Effects

The reactive oxygen and nitrogen species (ROS/RNS) present in plasma are the most important components in the use of gas plasma for the treatment of chronic and infected wounds and ulcers. ROS/RNS play a central role in antimicrobial efficacy and wound healing, as they are evolutionarily conserved signaling molecules that are naturally produced by the body during inflammation. The species are related to redox-mediated toxicity, alteration of biomolecules and signaling in cells. In addition to wound healing research, these aspects are also relevant for other clinically relevant diseases, such as oncology; helping to constantly develop new fields of application for the medical use of plasma technology.

The main task of the INP's "Plasma Redox Effects" research group is the identification and investigation of such new fields of application beyond descriptive wound healing to the mechanisms and concepts of therapeutic radicals of gas plasma technology and redox effects in cells. In recent years, the group has again been able to research various topics with funding from the BMBF, EU, DFG, Mecklenburg-Vorpommern state funds, the Head and Neck Tumor Research Foundation, the Ferdinand Eisenberger Foundation and the Gerhard Domagk Foundation, among others.

The projects included investigations into the antiviral effects of gas plasma technology as well as the optimization of plasma to combat antibiotic-resistant bacteria in wounds and redox-mediated effects following polymer exposure. Decisive progress was made in the field of combating bacteria by optimizing gas plasma treatment through the variation of gas admixtures, which led to the increased destruction of various bacterial strains, including antibiotic-resistant germs (Life, DOI: 10.33390/life13020257). The inactivation of coronaviruses by a neon plasma source was also demonstrated for the first time (Free Radical Biology and Medicine, DOI: 10.1016/j.freeradbiomed.2022.08.026).

The focus of the "Plasma Redox Effects" group is on translational topics in the field of oncology and tumor immunology as well as work to understand the mechanisms and complex



Combination therapy of malignant melanoma with plasma and checkpoint inhibitor leads to greater tumor reduction and alters gene regulation. DOI: 10.1002/advs.202303183

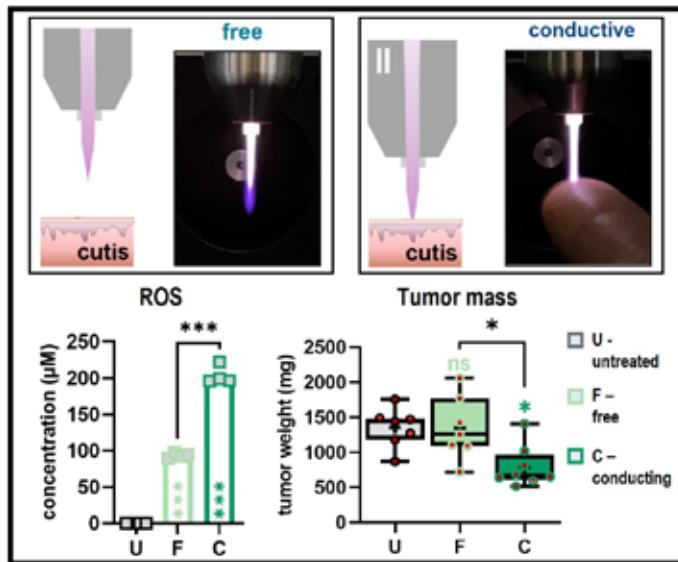
interactions of a tumor pathway tissue. The many aspects being investigated include, above all, the study of toxicity-associated redox effects and changes in biomolecules. Those are required for communication between cells and provide information for understanding inflammation-associated processes. Investigations with the greatest possible human relevance require the application of gas plasma technology in translational animal models.

A central result of the "Plasma Redox Effects" research group is the supportive treatment of tumors with plasma to enhance the effectiveness of other cancer therapies.

In a mouse model, it was shown that checkpoint inhibitor therapy in combination with plasma treatment leads to greater tumor reduction (Advanced Science, DOI: 10.1002/advs.202303183). The positive effects of combination therapy of malignant melanoma with systemic anti-PD1 antibody and local plasma treatment were based on reduced tumor growth and increased cell death.

The changes in gene expression led to an increased migration of immune cells into the plasma-treated tumor tissue, which provides evidence for the promotion of an endogenous anti-tumor immune response.

In a gene expression screen, a signature associated with immune cell activation was observed. This initial conceptual evidence was confirmed in a further study in colorectal tumor cells after treatment with plasma-treated fluid (PNAS, DOI:10.1073/pnas.2200708119).



Principle of optimizing gas plasma generated ROS/RNS by changing the distance between the plasma jet and the surface to be treated, which leads to different ROS/RNS entry and increased cell toxicity. DOI: 10.1016/j.freeradbiomed.2022.01.014 and 10.3390/antiox11081439.

The ROS/RNS-mediated effects led to cytotoxic activity and altered gene expression. Both were associated with increased immunogenicity and led to activation of immune cells. In primary urothelial carcinoma cells, plasma treatment also led to a change in gene expression, e.g. a reduction of a gene that is essential for the growth of tumor cells (Journal of Advanced Research DOI: 10.1016/j.jare.2022.07.12). Plasma treatment of the tumors, which were previously isolated from patients, also led to increased cytotoxicity.

A better understanding has been gained of the effect and mode of action of variations in plasma treatment intervals. For example, a short distance confers increased tumor toxicity, as more RNS/ROS are formed in dissipating plasma, which act directly on cells or tissue (Free radic Biol Med., DOI: 10.1016/j.freeradbiomed.2022.01.014). This decisive advance is particularly important for the application of cold plasma technology in the medical field in order to maximize the effects, such as tumor-reducing effects.

The increased toxicity of the new plasma mode was confirmed in a mouse model (Antioxidants, DOI: 10.3390/antiox11081439). One group received the pure liquid, one group received liquid that had previously been treated with plasma in non-diverting mode and the third group received treatment with the liquid that had been plasma-treated in diverting mode.

Compared to the non-diverting mode, a two- to three-fold increase in the amount of different ROS/RNS was measured in the fluid treated with diverting, which led to a successful tumor reduction. Treatment in non-diverting mode did not lead to any reduction. In addition, an increased amount of immune cells was found in the tumors, suggesting a promotion of an antitumor immune response by the plasma-treated fluid.

CONTACT



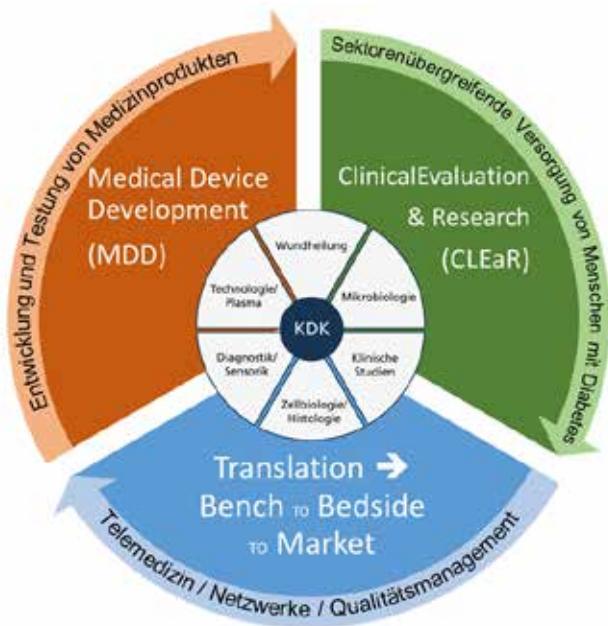
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Overview

The Kompetenzzentrum Diabetes Karlsburg (KDK) is a branch of the INP located at the Karlsburg Clinic. It stands for collaborative clinical research and supports the development of innovative medical products, therapies, technologies and diagnostics in the field of wound healing and plasma medicine. The short distances between clinic and research ensure a direct exchange between clinical staff and patients as well as researchers and industrial customers. This enables rapid product development with short iteration steps from the idea to market authorisation and direct feedback loops.

Thanks to this intensive collaboration and the short distances, research results can be transferred to clinical application much faster in cooperation with companies from the medical sector, which promises enormous time and financial benefits for the partner companies and ultimately also benefits patients because therapies are available to the general public more quickly.

The bilateral projects for testing newly developed plasma devices should be emphasised in this context. The KDK has thus built up expertise that is specifically used by external partners and increasingly companies in the field of cold plasma therapy to have their devices tested at the KDK and the INP based on DIN Spec 91315. Such services will continue to enrich the KDK's portfolio in the coming years. In future, the focus will increasingly be on the integration of sensor technology and AI in order to customise diagnostics and therapies even more to the individual needs of patients.



KDK - conception

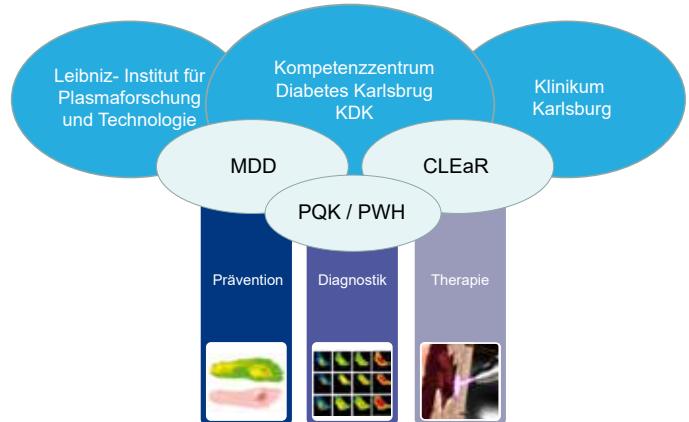
Application-oriented outlook

In terms of content, the KDK focuses on "research and development" of medical products and therapies for wound healing - always with the transfer to industrial and medical practice in mind. The foundation is formed by existing practical experience and technical expertise as well as the development of a quality management system. In the last two years, the focus has been on the further expansion of expertise for clinical application-oriented research as a mainstay in the field of diabetology and wound healing, primarily through joint projects in the areas of plasma medicine, wound therapy, diagnostics and prevention.

To this end, a quality management system is to be established in the medium term, which will enable the KDK to work with industry partners in compliance with ISO and MDR - which in turn should increase the attractiveness of the competence centre. At the same time, a network for cross-sector clinical testing and research will be established, in order to subject the medical devices developed in the projects to an initial clinical evaluation.

Projects on prevention, such as the smart insole ("Sensorsohle" project), and diagnostics, such as the fluorescence-based "Bacteria-Cam", were successfully completed. Other projects in the field of stem cell therapy, such as the "ActiHeal project" and the development of new, even more sensitive antibody diagnostics (AAk-Level project) for use for people with type 1 diabetes were also successfully completed in 2023. Furthermore, projects on measuring ion density by evaluating ion waves in plasma and accompanying modelling to identify the ions (MAID), research data management (NFDi4Ing), the use of plasma in care (AmbuPlas) and the design of a plasma jet array for medical applications based on the kINPen MED® (Multijet) have been worked on. These projects serve as the basis for the expertise that was established at the KDK during the start-up phase.

In the long term, sought-after services and preclinical tests will be certified in accordance with the relevant DIN/ISO standards. Over the next few years, a preclinical test centre for medical devices will be set up within the KDK in cooperation with other local partners, which is primarily geared towards the needs of customers in the context of medical device approval and offers a service for the rapid implementation of approval-relevant issues and the fulfilment of



KDK - structure

normative and legal product requirements. For collaborative projects in particular, products and diagnostics can be developed and tested in accordance with the applicable regulations, taking into account the relevant DIN/ISO standards. In particular, the inclusion of ISO standard 13485 for quality management with a focus on medical device development emphasises the special characteristics of the KDK for projects with small and medium-sized companies and spin-offs as well as larger companies.

To increase the visibility of the competences, a dedicated website was set up, which has been online since January 2022.

You can find more information about the KDK at <https://kompetenzzentrum-karlsruhe.de>.

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Plasma Source Concepts

The Plasma Source Concepts (PQK) research group is part of the Centre for Innovation Competence (ZIK) plasmatis and the Kompetenzzentrum Diabetes Karlsruhe (KDK). The ZIK plasmatis is an internationally leading centre in plasma medicine with a focus on wound healing. Within the KDK, PQK concentrates on the development of optimally adapted plasma sources for medical applications, in close cooperation with the "Plasma Wound Healing" research group. Founded in 2016, the KDK acts as a bridge between research and clinical application. It utilises a wide range of technological possibilities such as robotics, diagnostics and rapid prototyping.

PQK makes a significant contribution to the development of innovative medical products, particularly in the field of plasma medicine. The short paths between research and clinical application enable rapid iterations and accelerate product development through direct feedback from patients and doctors.

During the reporting period, PQK filled a key position in the area of research and development by appointing a PhD student. The position is aimed at researching the interaction of atmospheric pressure plasma jets, particularly in the context of gas flow distribution. The activities include optical and electrical diagnostics as well as the correlation of the results with gas phase modelling.

An open source code "BLITZ", a Python-based image viewer for fast loading of large image series, was developed for the first time. The programme enables efficient image analyses and statistical calculations, especially for plasma research. BLITZ was successfully released from beta and is available to the plasma research community.

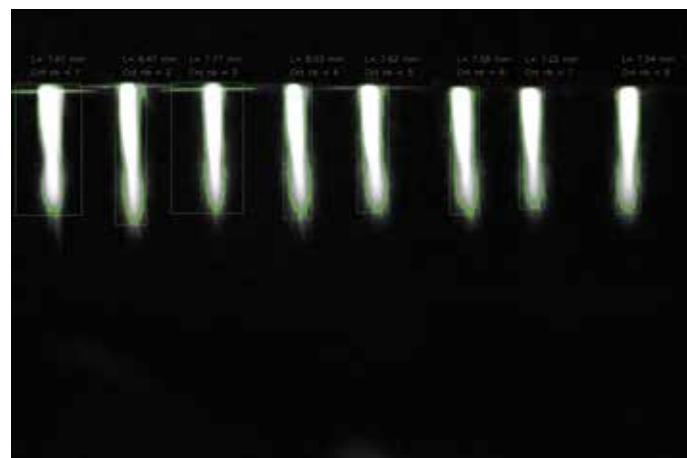
A new project to measure absolute ion densities (MAID) has been successfully acquired and launched. Funded by the German Research Foundation (DFG), the project focusses on the experimental determination of high-frequency current signals for the precise determination of the absolute ion density in plasma discharges under atmospheric pressure. The project includes the investigation of ion acoustic waves and symbiotic modelling in different discharge configurations, including dielectric barrier discharges.

The aim of the AmbuPlas joint research project is to develop a device for the outpatient application of plasma in wound care. In cooperation with partners, a standardised, mobile plasma application device is being developed and tested in a comparative application observation accompanied by the University Medical Centre Rostock.

The "P-Array" project aims to scale up plasma jet technology and increase mobility by means of an accumulator. At the same time, neoplas med GmbH is developing a device concept with an accumulator. Both approaches will be combined to create a device that fulfils the safety parameters and enables large-area treatments. The project responds to the need for targeted therapy for patients with large-area chronic wounds and is based on proven plasma medicine.

The biogeniV alliance, in which PQK is involved, was selected as one of 23 WIR! alliances. The alliance is dedicated to the utilisation of biogenic residues and pursues a regional, technologically innovative approach. The focus is on sustainable structures, unutilised potential and strengthening the regional profile through innovation. WIR! supports regions in identifying and implementing fields of innovation in order to drive structural change.

The NFDI4ING project addresses the challenges of implementing and using data, metadata and protocol standards in research laboratories, especially in smaller institutions without a centralised infrastructure. The project aims to develop



Automated qualification of the effluent length in an 8-fold arrangement of a plasma jet

a modular, open-source demonstrator for an open and easily adaptable laboratory infrastructure. The prototype networks simple sensor systems in accordance with the "FAIR Data Principles" and connects them to a central database.

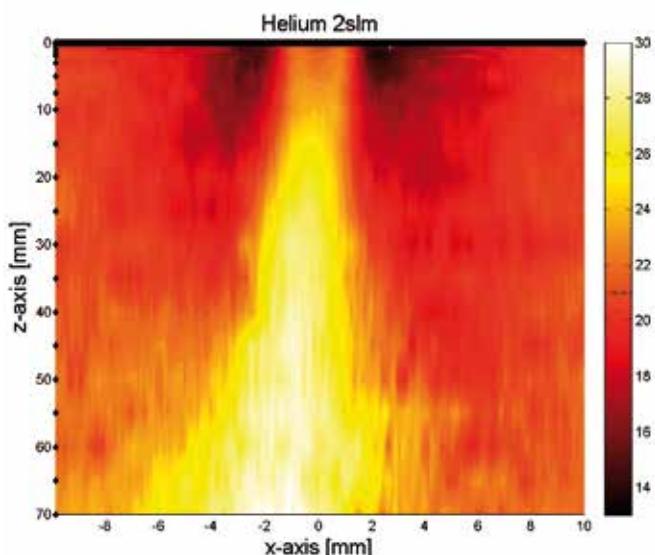
In response to the Covid-19 pandemic, the PlasmaPlusCorona project at the INP is developing innovative approaches to locally reduce the viral load in the respiratory tract using cold plasma technology. The interdisciplinary consortium of plasma physics, virology and medical institutes aims to transfer the technologies into proof-of-concept studies in animal models and thus make a contribution to combating pandemic threats.

The PeriPLas project with partners from industry and dentistry in Greifswald is working with PQK to develop an innovative treatment concept for peri-implantitis. The combination of mechanical cleaning, diode laser and cold atmospheric pressure plasma is intended to reduce inflammation and restore implant function. The ongoing multi-centre clinical study is nearing completion.

In the past project period, an international collaboration was established between the PQK research group and Brazilian partners. The focus was on the development of a portable plasma jet device for dental applications. In addition, investigating how this device can be used for the treatment of tracheal tubes in the context of the COVID-19 pandemic was in the focus. During a guest stay at the INP and the KDK, expertise in the characterisation of plasma sources for medical applications was applied for safety testing. Plasma jets can be modified using the MoNoS modular nozzle system:

the deposition area of reactive species increases and the ratio of air to plasma is stabilised. As part of a co-operation with INPs junior research group "Plasma Redox Effects", the reduction of cancer organoid growth was improved using Novel Modular Nozzle System (MoNoS).

Various student theses, internships and collaborations took place during the reporting period. From a previous master's thesis, a technical design for a wound size measurement system was discussed further, culminating in a project concept.



Investigation of the gas flow to characterise the Dufour effect - here the temperature profile without plasma ignition with a 2-slm helium gas flow

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Plasma Wound Healing

The research group "Plasma Wound-Healing" (RG PWH) deals with the question: Is the wound-healing-promoting effect of cold plasmas dependent on the aetiology of the wounds or also on the spectrum of microbiological colonisation? The individually optimised plasma treatment of different wounds plays a central role in applied clinical research. Furthermore, the topics of standardisation and safety of plasma sources are very much to the fore in the RG PWH.

Cold plasmas have a complex composition of free electrons and ions, UV radiation, visible light, mild heat and numerous excited species. In particular, the reactive oxygen and nitrogen species (RONS) together with UV radiation and electric fields are responsible for the biological effectiveness of the plasmas. These cold plasmas influence the cellular redox balance and can be adjusted to either stimulate or kill cells, depending on the composition and duration of treatment. The sensitivities of the treated cells differ greatly, which is due to the different antioxidant potentials of the various cell types and their ability to regenerate. Cold plasmas are therefore suitable for killing bacteria. Multi-resistant germs show the same reduction rates as non-resistant strains. However, it has been shown that a balanced plasma treatment of human cells can also lead to their stimulation.

The aim of the RG PWH is to transfer the basic results into the clinical application of wound treatment. Molecular mechanisms of the skin cells involved are to be analysed with regard to signal transduction and metabolism as well as cell repair in human



Plasma treatment of a chronically infected wound

skin cells and the immune system. For this purpose, wound swabs of so-called exudates are obtained and analysed for their cellular and soluble components.

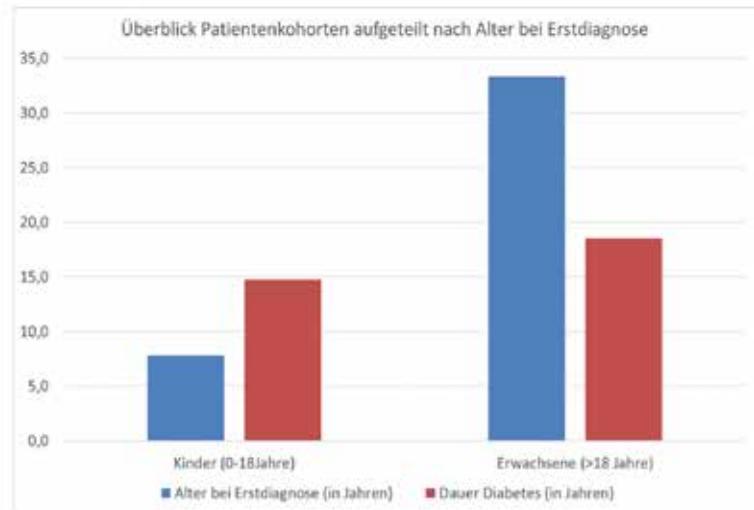
These examinations are carried out in close cooperation with the Karlsburg Clinic as part of the Kompetenzzentrum Diabetes Karlsburg (KDK). The aim is to establish a plasma treatment that is customised to the patient and the wound.

The clinical investigations include detailed analyses of wound exudates using both imaging and microbiological swabs. In addition to anti-microbial efficacy, the work of the RG PWH has also been shown to stimulate cell proliferation and cell migration through the effect of cold plasmas. Paracrine stimulation within the wound environment plays a key role here.

The cold plasma primarily activates the fibroblasts, which in turn emit messenger substances that have a specific effect on the human skin cells (keratinocytes) and thus indirectly contribute to wound healing.

In the AAk Level project, an innovative method of analysing antibodies in people with type I diabetes was developed together with the company Eurolimmun and the University Medicine Greifswald.

The aim was to isolate the autoreactive antibodies and their antigens from freshly collected sera and make them available to the partners for the development of an even more sensitive Enzyme-linked Immunosorbent Assay (ELISA) test system. The project also aimed to examine whether the radioimmunoassay (RIA) method currently used could be replaced by a fluorescence-based analysis.



Overview of the gender and age distribution of the test subjects

Autoantibodies against insulinoma-associated antigen-2 (anti-IA2) are an important marker for the diagnosis and prediction of new-onset type 1 diabetes mellitus (T1DM). Within the project, prototypes for two ELISA test systems were produced. A new prototype of an anti-IA2 ELISA and a further prototype of an anti-GAD65 ELISA were developed and successfully tested as part of this project.

Initial tests at Eurolmmun indicate a reduction in the overall incubation time. This speaks in favour of the high quality of the products. We hope that this will also lead to the decision that it can be further developed into a future product.

Samples from over 500 test subjects were included and analysed for this purpose. About 55% of the samples came from male participants and about 45% from women. As particular attention was also paid to the progression of diabetes in correlation with age at first diagnosis, a distinction was also made between children and adults when analysing the data.

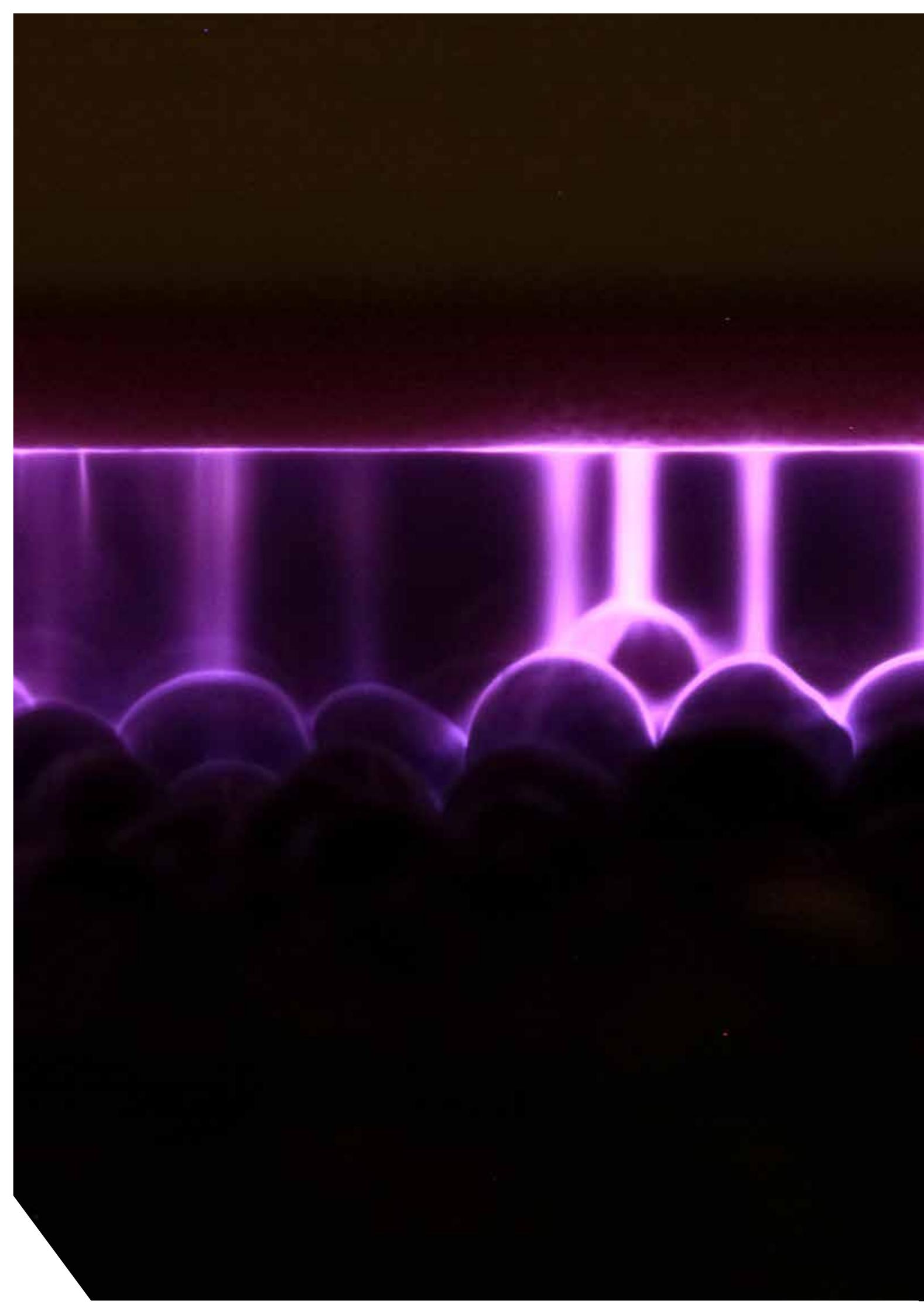
Overall, it can be stated that the number and quality of the clinical samples provided by the KDK made a decisive contribution to the success of the project. Both the clinical sensitivity of the prototype ELISA and the corresponding specificity far exceeded expectations at such an early stage of development. The method comparison revealed a sensitivity of the prototype ELISA of over 93.3 % in relation to the established ELISA and 93.8 %.

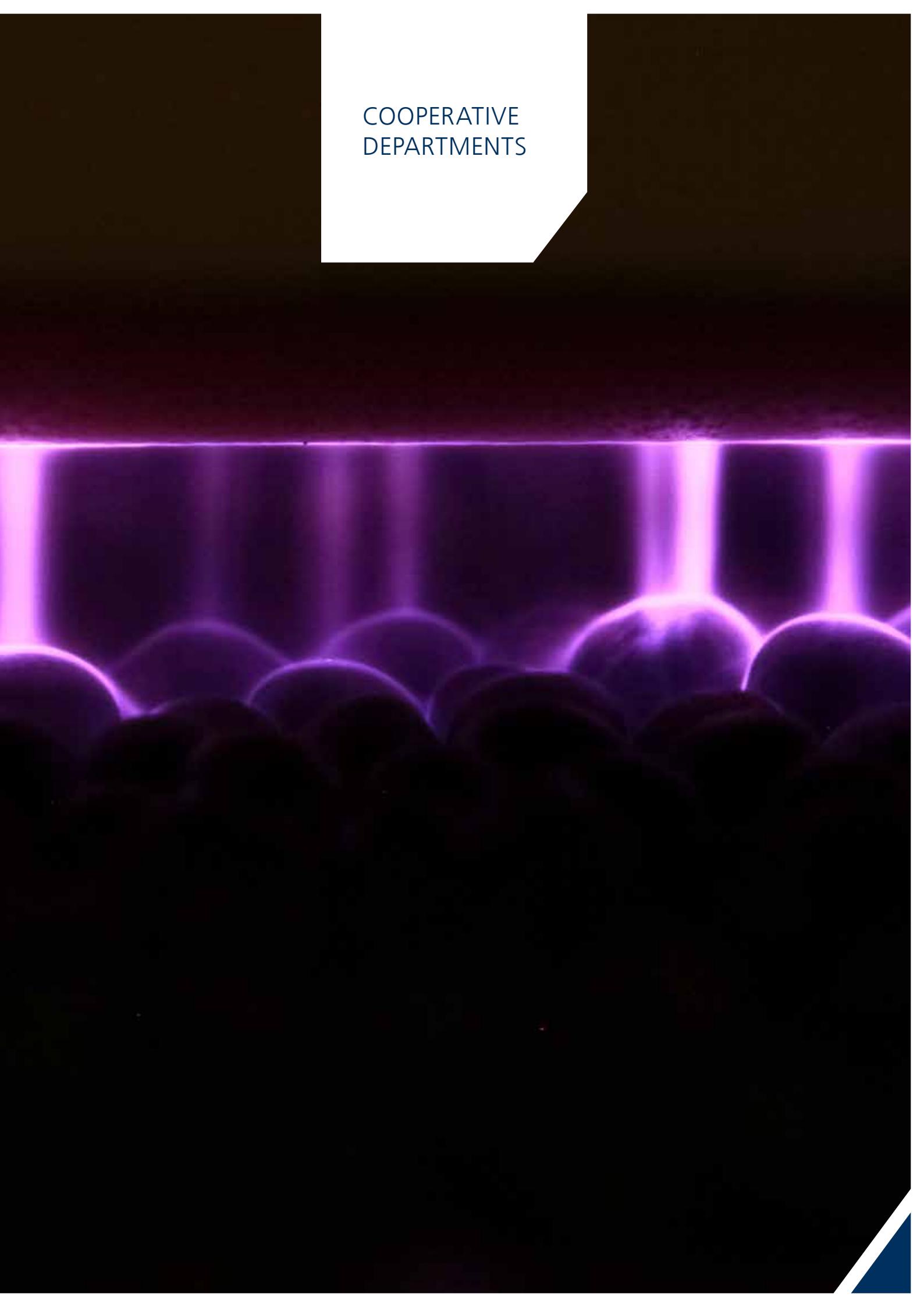
This means that the new assay already shows comparable data to the established standard in the development phase. These data suggest that the new anti-IA2 ELISA will be a valuable tool to support the serodiagnosis of T1DM. The reduction of the processing time to a few hours minimises the working time of the laboratory tests and strengthens the suitability of the prototype to replace the established ELISA.

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COOPERATIVE
DEPARTMENTS

Plasma Modelling & Data Science

The modelling and simulation of plasma sources and plasma processes is an essential supplement to laboratory experiments in plasma research. Model-based analyses of processes and parameter studies make it possible to optimise technological plasmas and open up new areas of application. As a result, the practical realisation of costly and time-consuming experiments can be reduced. In addition, model calculations also make it possible to determine physical variables that are difficult or impossible to access experimentally. In this way, fundamental phenomena can be investigated and the understanding of measurement data can be supported. At the INP, models of low-temperature plasmas at atmospheric and low pressure with scientific and technological utilisation potential are developed and applied. The spectrum of models ranges from the description of specific plasma effects to multi-physical modelling of plasma sources and plasma processes. Examples of applications include processes for layer deposition, reaction processes for the degradation or conversion of pollutants and switching technologies. The focus is on non-equilibrium descriptions, which are required for a consistent description of non-thermal and many thermal plasmas.

The modelling of plasmas includes various sub-steps. The first step is the development of an adequate model that captures all relevant effects in sufficient detail. Next, the problem-specific input data must be researched, evaluated and processed. The complexity of the overall description of plasma processes means that sub-problems, such as the reaction kinetic modelling of reactive plasmas, the determination of the electric field configuration, the kinetic description of electrons and ions and the treatment of radiation transport, are sometimes dealt with separately. However, the primary aim is to achieve a so-called self-consistent modelling. Here, all relevant phenomena are solved in a coupled manner. In this way, the interactions of the sub-problems can be adequately captured and predictive results can be achieved.

To solve the resulting system of ordinary and partial differential equations, which models and couples the various physical phenomena, suitable numerical methods must be developed or adapted and used appropriately. Depending on the problem, commercial software packages, open-source programmes or self-developed in-house codes are used for this purpose. The models and numerical methods adapted to specific problems at INP are characterised by high efficiency, stability and accuracy. Verification, validation and benchmarking of models and programmes are used on an ongoing basis to check and maintain the quality of the models and programmes developed. The model calculations and plasma simulations are carried out on high-performance

workstations and INP's HPC clusters. The availability of the high-performance computing infrastructure makes it possible to deal with complex, multi-dimensional problems.

The investigations are based on the current topics of the research programmes at the INP and are often closely linked to experimental work and executed in cooperation with national and international partners from research institutions

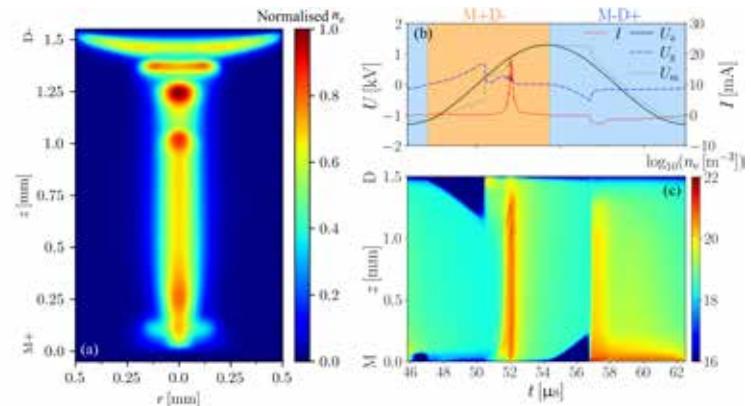


Figure 1: Modelling results of a single filament barrier discharge in argon at atmospheric pressure. Depending on the operating parameters, spatial layer structures (striations) appear along the discharge channel (a), which can be explained by a detailed analysis of the discharge process based on electrical quantities (b) and the electron density (c). The results have been published in Jovanović et al., *Plasma Sources Sci. Technol.* 32 (2023) 055011.

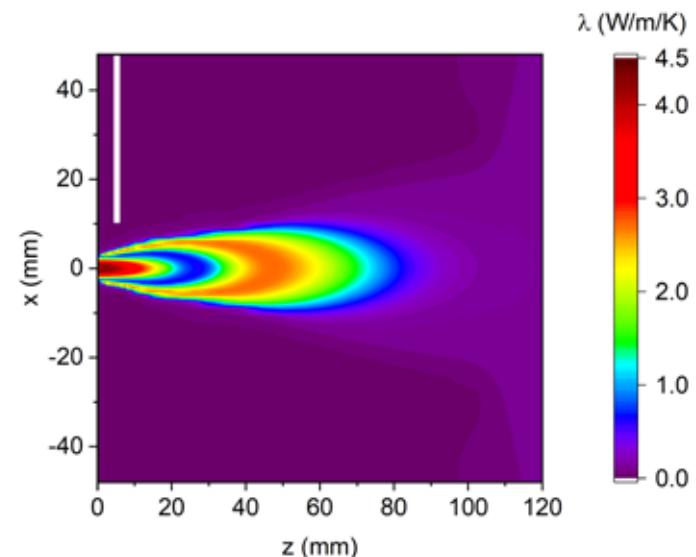


Figure 2: Modelling results of a plasma spraying process. The thermal conductivity λ in the plasma jet influences the heating of the injected particles. In contrast to operation in pure argon, it exhibits a specific pattern in Ar/H₂ gas mixtures. This leads to a spatially fluctuating heating of the particles. The results have been published in Zhu and Baeva et al., *Plasma Chem. Plasma Process.* 43 (2023) 1-24.

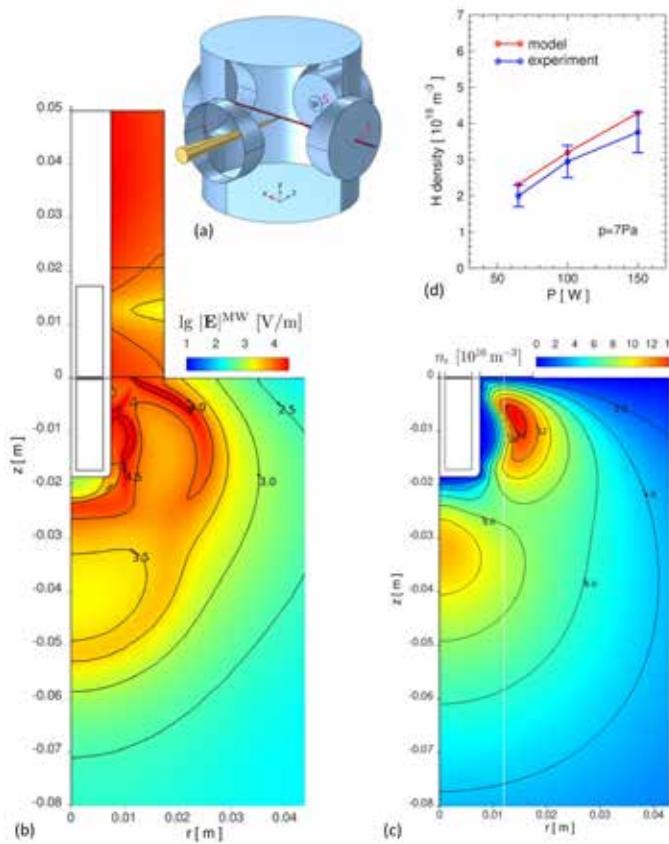


Figure 3: Modelling results of a low-pressure hydrogen plasma generated by an ECR source (a) at a power of 100 W and a pressure of 7 Pa. The structures in the microwave field (b) and in the electron density (c) illustrate the close mutual coupling of microwave propagation and plasma generation. The H atomic densities calculated for the centre of the reactor (a) agree very well with the values measured using LIF (d). The results have been published in Sigenerger et al., Plasma Sources Sci. Technol. 31 (2022) 105011.

and industry. In the field of thermal plasmas, the focus is currently on plasma torches and plasma spraying processes as well as investigations of spark and arc discharges. While the focus of the former is on optimising plasma applications, fundamental investigations are also being carried out, such as on the interaction of the plasma with the electrodes. Investigations of non-thermal plasmas primarily focus on plasma ion sources (ECR sources), barrier discharges and transient spark discharges. The focus is on studies of plasma-surface interactions, the optimisation of plasma-chemical processes and the stability of discharges. Among other things, fundamental model developments for self-consistent and spatially multidimensional fluid descriptions of application-relevant plasma effects take place here.

The close coupling of simulations and experiments is supported by structured research data management based on the FAIR data principles (FAIR = Findable, Accessible, Interoperable, Reusable), where the developments in the field of research data management are not limited to the local requirements. In exchange with the international community and linked to the establishment of the National Research Data Infrastructure (NFDI), the INP develops subject-specific solutions for data-supported plasma research that are recognised and used by the international community. Among other things, the INP operates the interdisciplinary plasma technology data platform INPTDAT and the metadata initiative plasma-mds.org, which supports the dissemination, archiving and re-use of data and information in the field of low-temperature plasma physics and plasma medicine. This work on research data management supports the application of modern data science methods, including automated and AI-supported data analysis. Further work in this area focuses on the use of machine learning methods to accelerate plasma simulations and on building knowledge graphs that link relevant data and information sources worldwide.

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Plasma Sources

The development and characterization of plasma sources and systems create a significant technological basis for the work of the INP. The cooperative department Plasma Sources has a broad spectrum of specialist and methodological expertise in this area. Main areas of expertise lie in the technical, engineering and physical fields. Devices and systems are developed in close coordination with the research programmes in accordance with the requirements of the respective applications. Development and application documentation as well as application-adapted, basic characterization complete the development process. Integration into complete systems and the development of peripheral modules such as high-voltage generators are also carried out.

A particular focus is on activities for the development of atmospheric pressure plasma systems. A modular design of the devices facilitates versioning, iterative further development and integration into complete systems if required. For the development of the devices, the INP has special laboratories in which the plasma sources are designed, manufactured and characterized. Components and assemblies can be manufactured directly on site using rapid prototyping technologies such as 3D printing and laser cutting processes. This enables the direct implementation of novel plasma source concepts in devices.

The Plasma Sources department is often primarily responsible for work up to medium technology readiness levels

(TRL), i.e., up to the prototype stage. During development, the department also works together with partners from industry and realizes technology transfer.

The range of tasks of the Plasma Sources department includes the design and construction of electrical and mechanical assemblies. Electrical and electronic circuits are designed and functionally simulated. Circuits are also implemented in printed circuit boards, which are manufactured on site. Mechanical assemblies are developed in CAD workflows and manufactured using the optimum technology depending on the requirements for materials and design features.

State-of-the-art 3D printing and laser cutting processes complement conventional methods, for which the Plasma Sources department cooperates very closely with the INP's mechanical workshop.

Among other things, components can be additively manufactured from different metals out of CAD models using selective laser melting, whereby geometries can even be realized that cannot be implemented using conventional manufacturing methods.

The basic characterization of the developed plasma systems is carried out by electrical, optical and spectroscopic investigations. This area includes FTIR spectroscopy for gas phase and surface analysis, by which plasma-generated reactive species can be detected and the influence of plasmas on the surfaces of the components used can be investigated.

In addition to the development and production of devices and systems, the Plasma Sources department also carries out checkups for the entire INP, maintains and repairs devices provides technical support for our partners. The devices developed, supplied and supported are used for a wide range of applications. Important examples of this are:

Agriculture

For research purposes in agriculture, plasma sources are used to treat seeds, for example to improve their germination rate. In addition to a high throughput at low operating costs, these sources must ensure uniform treatment of the seeds. Plasma systems are also used to treat liquids. Water can thus be enriched with disinfectant components, such as an acidic mixture of nitrite and hydrogen peroxide, or even serve as the basis for efficient, sustainable fertilization strategies via a solution of nitrate. The plasma process obtains the reactants for all dissolved components from the ambient air.



System for uniform treatment of seed with atmospheric pressure plasma at high throughput.

Medical plasma sources

Like all products used in medicine, the development of medical plasma sources is subject to enhanced requirements. These requirements are met by taking into account the legal requirements (e.g., electrical safety standards) as early as the development stage. In addition, analyses of approval-relevant parameters, such as irradiance levels and leakage currents, are carried out. In addition to desktop devices with a mains connection, fully integrated, self-sufficient handheld solutions are increasingly being developed.

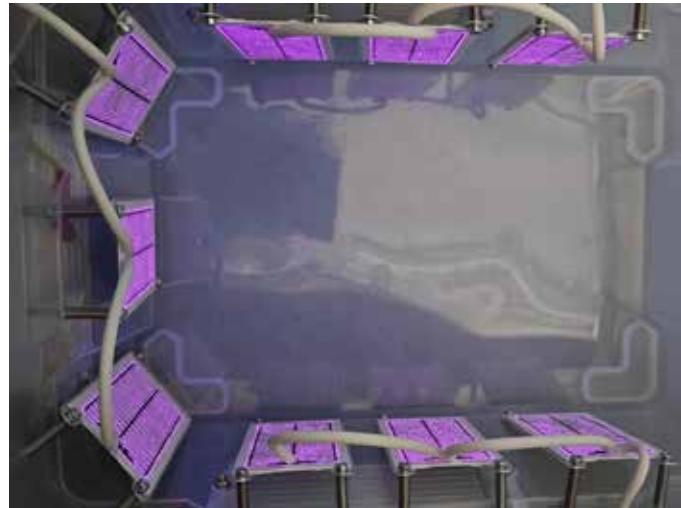
Decontamination

Plasma sources for the treatment of chemical or microbiological contamination are designed as assemblies for integration into application-specific devices and systems. These sources are used in room air hygiene, exhaust gas treatment or for the decontamination of surfaces. Another focus is on plasma systems for the degradation of contaminants in water and systems for the gentle extraction of ingredients from biomass.

Peripheral devices and systems

The plasma sources can interact with other modules for diagnostic, control and regulation purposes via clearly defined interfaces. To ensure optimum compatibility between different components, close coordination with project and research partners always takes place during development. In addition to the plasma sources, peripheral devices and systems are also developed in-house as required.

Due to the large number and variety of systems developed and supported, the department's internal data management has been further expanded in 2022 and 2023. In addition to the already established plasma sources' catalog, the developed systems will be integrated into the INP's electronic lab notebook system, making it even easier to use the systems to generate research data that complies with the FAIR principles.



Experimental setup for the investigation of plasma applications for large-area decontamination of the lower extremities of patients in combination with vacuum therapy.

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Plasma Life Science

Since 2022, the Plasma Life Science group has been organized as one of three cooperative departments. In addition to the Plasma Modeling & Data Science Group and the Plasma Sources Group, the Plasma Life Science Group also works together with several research programmes of the INP and contributes its expertise and methods to the successful processing of research projects. Research into the fundamentals, effects and possible applications of cold atmospheric pressure plasma in the life sciences opens up a wide range of areas of work. Projects have been realized primarily in the research programme Agriculture, Bioeconomy & Environment, but also in the research programme Plasma Medicine and at the Kompetenzzentrum Diabetes Karlsruhe. In order to cover a broad range, the target organisms and media investigated are correspondingly diverse and range from bacteria to microalgae, cells and tissues. In addition, technical facilities have been created to comprehensively analyze liquids of different origin.

The antimicrobial effect of plasma focuses on the decontamination and inactivation of bacteria and fungi and can be used for various targets such as liquids, air or surfaces (biotic, abiotic). The use of cold plasma for reducing microorganisms in the therapeutic treatment of wounds is one important aspect in medical applications.

Over recent years, the possibilities of plasma applications have been increasingly investigated in the fields of bioeconomy and environment. The Plasma Life Science group is well positioned to work on these topics. For example, it investigates ways of breaking down microalgae in order to extract their bioactive components. Furthermore, plasma-assisted processes are researched with the aim of breaking down environmental chemicals in waste water. The use of plasma technology in aquaculture systems without harming the fish's health is another research topic that combines several aspects.

In addition, clinical plasma applications are accompanied by microbiological and molecular biological laboratory analyses and new applications are supported. In addition, new plasma sources are tested with standardized tests with regard to their biological efficacy, effectiveness and safety.

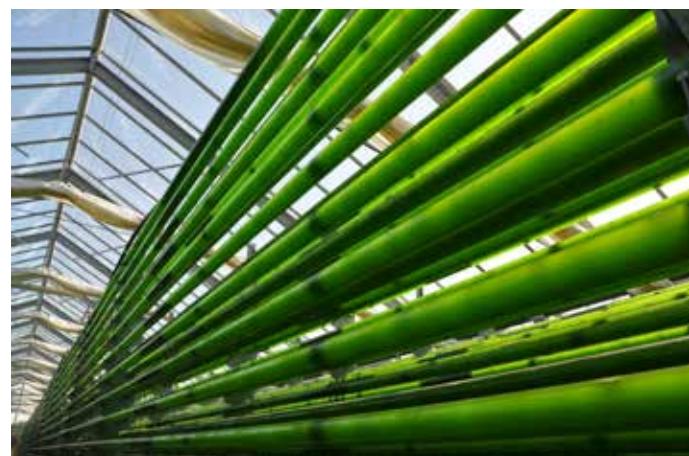
The following expertises and technological equipment are available:

Liquid analysis

Various chromatography systems (IC - ion chromatography, HPLC - high-performance liquid chromatography) that can be used to analyze changes in ion composition (e.g. nitrate, nitrite) or special substances such as amino acids in plasma-treated liquids. The application-oriented analysis also includes chemical analyses of, for example, industrial waste water and the measurement of the total organic compound content.

Protein analysis

Various techniques for the quantitative and qualitative analysis of proteins. In addition to standard methods of protein detection in multi-plate format (ELISA, photometric assays), Western blots using membrane transfer and a high-throughput capillary system are also available. Samples for mass spectrometric analyses (by Plasma Redox Effects) can be generated using well-established protocols.



Pipesystem for the cultivation of microalgae with reduced use of water surface and independent of seasonal conditions. (photo: Algenfarm Klötze)



Experiments with salmon and plasma treated water and plasma treated water as ice were conducted with a guest scientist from Norway. The samples were inoculated with listeria and serve as test subjects.

Microalgae

The laboratory equipment and expertise for cultivation of microalgae with subsequent extraction using plasma technologies are available and ready for use. Bio-active components can be determined in combination with other analytical methods.

Outlook

The broad spectrum of methods and expertise opens up a wide range of topics for the Plasma Life Science department, from clinical to industrial research in the field of bioeconomy. Most of the existing methods and expertise can be excellently combined and complemented with each other. This can result in a multitude of further research opportunities for the entire INP.

Cell culture and histology

Expertise and equipment for carrying out histological analyses. Through close cooperation with clinical partners, we are also able to conduct and support patient-oriented research. Thin tissue sections are prepared from excised tissue samples using a cryomicrotome or a normal microtome. This is followed by immunohistochemical staining or immunofluorescence. These histological techniques are also used for animal experiments, which are realized by collaborative partners.

Microbiology

Performance of all common microbiological tests, e.g. quantitative live cell counting using a spiral plate system, safety cabinets for sterile work, spectrophotometer for determining optical density. An existing strain collection includes a large number of bacteria (including microorganisms of risk group L2), yeasts and fungi. Plasma sources to be tested can be set up directly in the laboratories and can be connected to the in-house gas supply. Applications range from liquids, environmental samples, food to surfaces as test media.

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INP
Darmstadt

SUPPORT DEPARTMENTS



Organization, infrastructure, management and support for scientists

Modern research institutions require professional science management, a lean and efficient administration and a modern infrastructure tailored to the needs of a research institution. At the INP, this is professionally guaranteed in the organizational units, Administration and Infrastructure, the Management Support and in specialized management units that report directly to the Board of Directors.

These organizational units see themselves as service units for the researchers and therefore play an important role in the success of the institute.

Administration and Infrastructure

The "Administration/Infrastructure" department at the INP is an essential addition and organizational support for the specialist departments and groups. It organizes the smooth running of operations and comprises the four departments "Human Resources" (including travel expense management), "Finance" (with procurement, accounting, asset and third-party funding management), "Infrastructure" (with facility management and mechanical workshop) and "IT".

The INP maintains a data network for data processing, is constantly expanding it and maintains the connection of the INP network to external networks. The provision of a modern, powerful and, above all, secure IT infrastructure is essential for a research institute like the INP. The further digitalization of administrative processes will become even more important in the coming years.

The complexity of the applicable legal regulations in the areas of public procurement law, procurement, financial accounting, taxes, accounting of the commercial financial years and third-party funding management, which a modern research institute must implement, has steadily increased in recent years. It is therefore an important task of the administration, especially the "Finance" department, to adequately support scientists in the implementation of administrative tasks and to provide assistance so that they can concentrate on their research tasks.

	2022	2023
Number of ongoing projects	137	137
Third-party funding volume	17,66 Mio. €	10,97 Mio. €
Number of award procedures	90	53
Number of orders	2.500	2.300
Number of transactions by financial accounting	4.702	4.533

The "Infrastructure" department is responsible for the building technology, the facilities and the building of the institute as well as all construction measures for the technical equipment and the smooth integration of the new work areas in the Center for Life Science and Plasma Technology, which went into operation in 2023. The "Infrastructure" department also includes the institute's mechanical workshop, where workpieces for the scientific experiments are manufactured.

The "Human Resources" team is responsible for all administrative tasks relating to our employees. In addition to coordinating job advertisements, employment contracts, payroll accounting and supporting the onboarding and offboarding of new colleagues, the colleagues also keep an eye on the health of the workforce and organize the mandatory and additional company medical check-ups as well as other additional health services.

Research management

Management Support and specialized management units Around half of the INP's total budget is competitively acquired third-party funding from federal and state ministries, the German Research Foundation, the European Union and industry. The organizational unit "Management Support" advises the Executive Board, the heads of the research divisions and the research programmes in matters of research strategy and research policy. It has the task of advising and supporting INP researchers in the acquisition of third-party funding. It provides information on new funding guidelines and is jointly responsible for the preparation of applications. It acts from the perspective of the funding bodies and thus contributes to improving the quality of project applications. In addition, the Management Support unit assists technology and knowledge transfer as well as process management and is responsible for its own projects. It also supports the institute in the implementation of large-scale projects by deploying project coordinators.

Since 2020, various overarching special tasks have been assigned by central, supporting management units. Specifically, these are the "Communication" unit with the tasks of public relations, internal communication and event management, the "Legal and Patents" unit responsible for legal issues and patent matters and the "Special Tasks" unit, which is responsible for the management of major projects, for example.

Knowledge & technology transfer

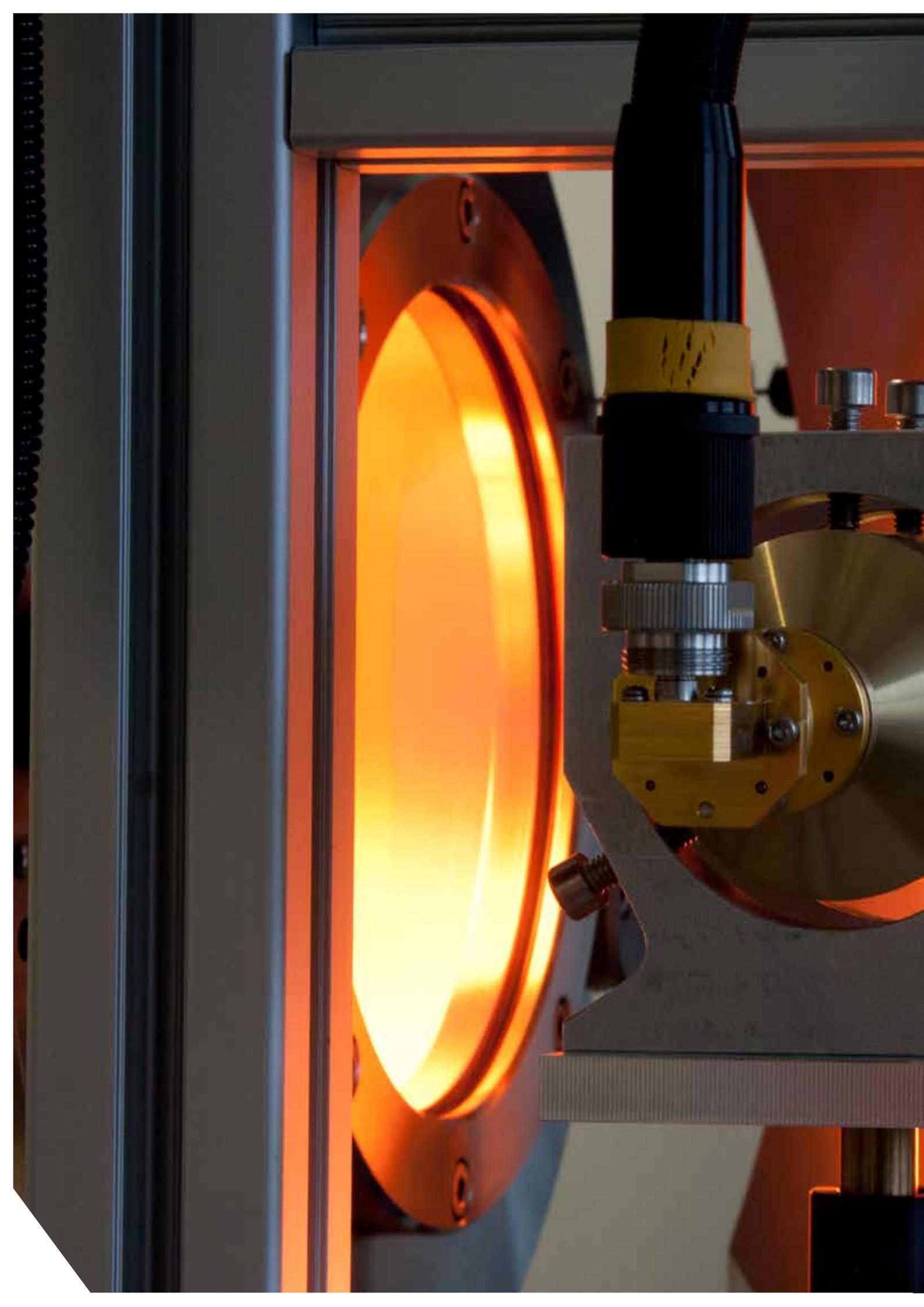
The institute's motto - FROM IDEA TO PROTOTYPE - does not only outline the statutory mission of conducting application-oriented basic research, but also the use of the research results obtained. The INP carries out publicly funded research projects in order to increase knowledge on socially relevant topics. The Institute continuously publishes the results of these projects in peer-reviewed journals, at national and international conferences, trade fairs and at events for the general public.

For application-relevant topics that are of economic interest, the INP makes its knowledge available as a service provider as a customer solution. These mostly bilateral industrial projects help companies to benefit directly from the latest research findings at the INP.

For its own technology transfer, the INP supports the institute's own spin-offs according to the motto "From prototype to product". Knowledge that is commercially exploitable and is not initially to be offered as a unique customer solution can be developed to market maturity in a new spin-off: "From prototype to market". In recent years, the following spin-offs followed this principle:

neoplas GmbH (2005)
neoplas control GmbH (2006)
neoplas med GmbH (2009)
COLDPLASMATEC GmbH (2015)
Nebula Biocides GmbH (2019)

Two further spin-offs are in preparation and are scheduled to start their operation in 2024.





APPLICATION
LABORATORIES

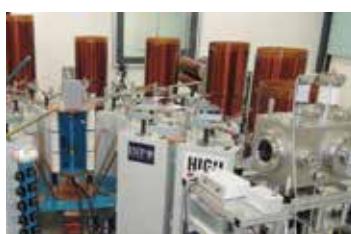
Application laboratories at the INP

The INP has a wide range of diagnostic methods for the analysis of plasma processes and plasma sources with a special focus on applications and for users. Here you can get an overview of our application laboratories:



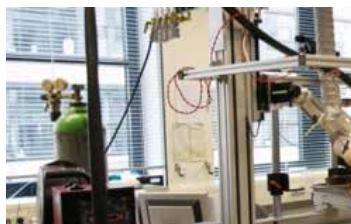
Laboratory for surface diagnostics

The laboratory has state-of-the-art technical equipment for analysing the properties of materials as well as the interaction of these materials with their environment. In addition, new types of material surfaces, which have special functions, are produced here using plasma technology.



Arc laboratory

With specific test arrangements and the unique coupling of specific diagnostics, statements can be made about the reliability and service life of switchgear in low, medium, or high voltage technology.



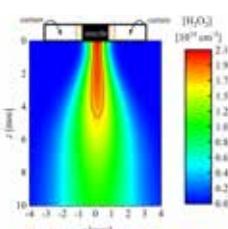
Arc welding laboratory

In the laboratory, welding processes are simulated under practical conditions in order to carry out investigations into process reliability, stability, and efficiency in arc welding using the latest measuring equipment.



High current/high voltage laboratory

The focus is on the development of methods and processes that increase the service life and reliability of electrotechnical equipment with special consideration of the environmental compatibility and energy efficiency.



Plasma diagnostics laboratory

The focus of this laboratory is on different diagnostics, especially for the characterisation of atmospheric pressure plasmas. For example, important parameters such as electron density or atomic and molecular particle densities are quantified here in different sources.



Microbiological laboratory

The microbiology laboratory is a safety level 2 laboratory in accordance with Section 44 of the German Infection Protection Act (IfSG), which permits activities with pathogens in accordance with Section 49 of the IfSG and Section 13 of the German Biological Substances Ordinance. In addition, the laboratory has an excellent network of accredited and certified testing laboratories in the field of hygiene and can therefore draw on a wide range of expertise.



Laboratory for plasma decontamination

This laboratory develops plasma sources and processes for the disinfection and sterilisation of bio-relevant materials and medical devices. A particular focus is on food sterilisation. In addition to various plasma diagnostic methods (OES, LIF, MW interferometry), in-house microbiological laboratories are available for testing and optimising the systems.



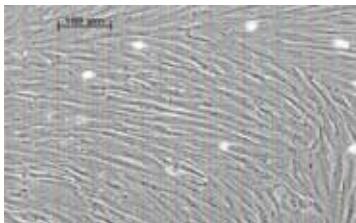
Laboratory for high frequency technology

The laboratory focuses on the provision, optimisation, and development of methods and systems in high-frequency technology. Their use ranges from the small signal range for diagnostic applications to the large signal range for driving microwave plasma sources.



Synthesis laboratory for green ammonia materials

Expertise in thin-film and nanomaterial synthesis using plasma-based vacuum processes for material synthesis is concentrated in this laboratory. In combination with in-house engineering expertise, this laboratory paves the way for innovative material and coating design for sustainable ammonia technologies and energy applications, corrosion protection and barrier coatings.



Laboratory for life science applications

A comprehensive range of modern analytical and molecular technologies is available. The influence of plasma on biological systems can be studied at different levels of complexity, ranging from organisms, tissue samples or 3D cell cultures (spheroids), cells to sub-cellular molecules.



Laboratory for materials characterisation

A full range of analytical techniques for the preparation and analysis of materials is available in this laboratory. Electrochemical techniques are also available. An addition to the portfolio is equipment for the determination of gas permeation (hydrogen, oxygen) in materials.

MISSION STATEMENT

We see ourselves as the leading institution in Germany in the field of plasma research and technology in the comprehensive combination of basic research and applications.

As part of the Leibniz Association, the INP is a non-university research institution engaged in application-oriented fundamental research on low-temperature plasma physics.

GOOD SCIENTIFIC PRACTICE

We deliver excellence in science and technology through good scientific practice.

Our research work is conducted in accordance with the guidelines for ensuring good scientific practice of the Leibniz Association and the DFG. This includes a consistent orientation towards the international state of the art in research and technology, the continuous development of scientific methods, a thorough working method including critical thinking, a deep respect for the scientific work of the individual, and the promotion of broad cooperation.

STRATEGY

The realisation of long-term goals and sustainable results is the strategy of the Institute.

The institute ensures a creative environment with the aim of offering its employees the best possible working conditions and opening up new perspectives. Future-oriented topics of overall social and international relevance and with high scientific standards are the focus of our work. On the basis of a sound overall strategy, it is thus possible to help shape trends in politics, business, and research.

EQUAL OPPORTUNITY

We offer fair and balanced living and access opportunities for all.

The INP is actively committed to gender equality. It also provides opportunities for persons with disabilities and creates family-friendly working conditions. The topics of equal opportunities, freedom from discrimination, family friendliness and compatibility of family and career are an integral part of the institute culture at all organisational levels. We see it as the responsibility of all of us to live and ensure this.

COMMUNICATION AND SPIRIT

We are open, fair, and respectful with each other.

We respect cultural diversity. Interdisciplinarity and cooperation within the institute are the basis of our success. We encourage independent action and codecision by all employees in the areas of responsibility based on the matrix structure.

PROMOTION OF YOUNG TALENT

We promote young talent at all levels of the institute – and beyond.

In the competition for the “best minds”, the promotion of young talent in all fields of activity is of particular concern to us. With our application-oriented fundamental research, we inspire the next generation for topics relevant to society as a whole. We enable specific experiences in research and in cooperation with industrial partners. For us, the promotion of young talent includes all phases of qualification – from school, studies, and apprenticeships to career.

INTERNATIONALISATION

We operate both nationally and internationally.

From Greifswald, we cooperate with internationally recognised research institutes. We help our scientists take advantage of international exchange opportunities and promote the research fellowships of international colleagues at our institute. The active participation in shaping the European Research Area is one of our priorities.

TRANSFER OF RESEARCH SERVICES

The results of our research have both social and economic benefits.

Our research is realised in specific applications. This includes the publication of scientific results and their transformation into both products and services.

Gender equality and reconciliation of work and family life

High-quality results can be achieved only at a research institute with highly motivated employees. They must be given the best possible encouragement in their professional and personal development by their managers as well as support when it comes to balancing a career and family. The Leibniz Institute for Plasma Science and Technology (INP) is therefore actively committed to gender equality. This is an integral part of the philosophy of the INP and is anchored in the statutes and guidelines of the institute. This issue receives considerable attention from the Institute management in terms of strategic planning for gender equality and the implementation of individual activities. In the past two years, the proportion of women has been maintained at around 40%.

Because good commitment to gender equality is more than quotas and laws, we create specific family-friendly working conditions: The services offered to our employees range from individual working time and work location agreements, including an agreement on "mobile working" that is currently in force, to a parent-child room that can be used in the event of childcare shortages.

Our employees come from a wide range of nations and have varied career paths. We are committed to equal opportunities and non-discrimination at all levels of the institute. We support our employees with customised personnel development opportunities, which are discussed in regular meetings. In 2021, the Gender Equality Officer and her deputy have supported the successful application for the "HR Excellence in Research Award" of the European Commission. The award is a sign that the INP cares about creating an ideal working environment for excellent research.

We have already received three TOTAL E-QUALITY awards for our gender equality work. In 2020, we applied for a further extension and were once again able to convince the jury with our gender equality work. TOTAL E-QUALITY Deutschland e.V. recognises the successful and sustainable commitment of organisations and companies to equal opportunities in the workplace. The award was developed with the help of the Federal Ministry of Education and Research (BMBF) and the European Union and is given for exemplary action in the sense of personnel management oriented towards equal opportunities.

The work of the Gender Equality Officer is an important driver for further strengthening equality at the INP. New elections for the position of Gender Equality Officer and Deputy Gender Equality Officer are scheduled for spring 2022. The Gender Equality Officer has their own budget with which they can set priorities in their work. In close cooperation with the Board of Directors and the works council, the Gender Equality Officer organises workshops and advises employees on issues such as reconciling family and work.



Recognition for successfully implemented equal opportunities awarded by TOTAL E-QUALITY Deutschland e.V.

Rostock	Greifswald	Karlsruhe
Scientific Advisory Council Chair: Dr. U. Kaltenborn	General Assembly Chair: Dr. W. Blank	Board of Trustees Chair: Dr. B. Schulte
Chairman of the Board and Scientific Director: Prof. K.-D. Weltmann / Chief Financial Officer: J. Berger Scientific Board Members: Prof. D. Uhrlandt & Prof. T. von Woedtke		

Research Divisions and Programmes								
Renewable Energies & Bioeconomy Prof. K.-D. Weltmann			Plasma Chemistry & Process Technology Prof. D. Uhrlandt			Health & Hygiene Prof. T. von Woedtke		
Research Factory Dr. J. Hummel	Green Energy Technologies Dr. A. Kruth	Agriculture, Bioeconomy & Environment Prof. J. Kolb	Plasma Chemical Processes Prof. R. Brandenburg	Thermal Plasma Technologies Dr. D. Gonzalez	Plasma Surface Modification Dr. F. Hempel a.i.	Plasma Medicine Prof. T. von Woedtke	Kompetenzzentrum Diabetes Karlsruhe PD Dr. P. Augstein Dr. U. Netz	
	Green Ammonia Materials Dr. A. Kruth	Plasma Process Technology Dr. V. Brüser	Plasma Diagnostics Dr. J.-P. van Helden	Plasma Radiation Techniques Dr. S. Gortschakow	Plasma Surface Technology A. Naumann	Plasma Redox Effects Dr. S. Bokschus	Plasma Source Concepts Dr. T. Gerling	Plasma Wound Healing Dr. K. Masur
	Plasma Bioengineering Dr. J. Ehlebeck				Biosensing Surfaces L. Barillas-Mora			
Cooperative Departments								
	Plasma Modelling & Data Science Dr. M. Becker			Plasma Sources Dr. R. Bansemer		Plasma Life Science Dr. S. Hasse		
Administration and Support Departments								
	Management Support Dr. H. Sawade			Board Departments Board of Directors		Administration & Infrastructure J. Berger		

Board of Trustees

The Board of Trustees is the supervisory body of the INP to which the members of the state and federal government also send their representatives.

It decides on all essential scientific, economic, and organisational issues of the INP.

Members (2023)

Dr. Björn Schulte
Bundesministerium für Bildung und Forschung

Woldemar Venohr
Ministerium für Bildung, Wissenschaft, Kultur, Bundes- und Europaangelegenheiten
Mecklenburg-Vorpommern

Prof. Dr. Elisabeth Prommer
Universität Rostock

Prof. Dr. med. Wolfgang Motz
Klinikum Karlsruhe

Dr. Christiane Gebhardt
Schweiz

Prof. Dr. Albert Sickmann
Leibniz-Institut für Analytische Wissenschaften – ISAS – e.V.

Scientific Advisory Council

The Scientific Advisory Council is the advisory body of the INP. The members active in the research field of the institute include internationally renowned scientists from university and non-university research as well as industry. The Scientific Advisory Council advises the Board of Trustees and the Board of Directors on all important scientific and organisational issues, in particular on long-term research planning.

Members (as of 2023)

Dr. Uwe Kaltenborn (Vorsitzender)
HIGHVOLT Prüftechnik Dresden GmbH
Dresden

Prof. Dr. rer. nat. Martina Meinke
Charité – Universitätsmedizin Berlin

Prof. Dr. Luc Stafford
Chaire de recherche du Canada en physique des plasmas hautement réactifs (PPHARE), Montréal

Dr. Volker Goeke
Linde GmbH, Pullach

Prof. Dr. Dr. h.c. Manfred Thumm
Karlsruhe Institute of Technology (KIT)

Prof. Dr. Satoshi Hamaguchi
Osaka University - Center for Atomic and Molecular Technologies (CAMT)

Prof. Dr. Annemie Bogaerts
University of Antwerp

Prof. Dr. rer. nat. habil. Ursula van Rienen
Fakultät für Informatik und Elektrotechnik,
Universität Rostock

Prof. Dr. Alexander Fridman
Drexel University

Dr. Eric Robert
GREMI, Orleans

General Assembly

The general Assembly is the highest decision-making body of the INP. It elects the Board of Trustees, decides on amendments to the statutes, receives the report of the Board of Directors on the general situation of the INP, and approaches the activities of the Board of Directors.

Members (as of 2023)

Dr. Wolfgang Blank (Chair)
WITENO GmbH

Dr. Bjoern Schulte
Bundesministerium für Bildung und Forschung

Woldemar Venohr
Ministerium für Bildung, Wissenschaft, Kultur, Bundes- und Europaangelegenheiten
Mecklenburg-Vorpommern

Prof. Dr. Dagmar Braun
Braun Beteiligungs GmbH, Greifswald

Prof. Dr. André Melzer
Universität Greifswald

Dr. Stefan Fassbinder
Oberbürgermeister Universitäts- und Hansestadt Greifswald

Mario Kokowsky
DEN GmbH

Prof. Dr. Jürgen Meichsner
Universität Greifswald

Dr. Arthur König
Ehemaliger Oberbürgermeister Universitäts- und Hansestadt Greifswald

Facts and figures

Budget

The total budget amounted to €28.4 million in reporting year 2022 and €22.6 million in reporting year 2023. Personnel expenses in 2022 as well as in 2023 were €13.1 million, and operating expenses were €6.9 million (2022) and €7.3 million (2023). €7.6 million were invested in INP equipment in 2022 and €2.5 million in 2023.



Personnel

As of January 2023, the INP has 202 employees, 123 of whom work in scientific and technical areas and 79 in scientific support. Just over 38.5% of employees are women.



Memberships of the INP

- 3D-Druck-Netzwerk
- BamS
- Bundesverband mittelständischer Wirtschaft
- CLEANTECH Initiative Ostdeutschland
- CCC-MV
- DECHEMA
- DekubiTel
- Deutsche Gesellschaft für Plasmatechnologie e.V. (DGPT)
- Deutsche Physikalische Gesellschaft e.V. (DPG)
- enviIMV - Clean Technologie & Innovation aus Mecklenburg Vorpommern
- Europäische Forschungsgesellschaft Dünne Schichten e.V. (EFDS)
- FoodSystems
- Forschungsvereinigung Schweißen (DVS)
- Forum medTech Pharma
- German Water Partnership
- Greifswald University Club (GUC)
- Informationsdienst Wissenschaft (IdW)
- Initiative Chronische Wunden e.V.
- Institut für Energie- und Umwelttechnik e.V. (IUTA)
- Institute of Electrical and Electronics Engineers
- Kompetenznetz Industrielle Plasma-Oberflächentechnik e.V. (INPLAS)
- Leibniz Forschungsverbund Gesundheitstechnologien
- Leibniz-Netzwerk für Immunvermittelte Erkrankungen
- Nationales Zentrum für Plasmamedizin e.V.
- Netphasol
- Plasma for Food
- Plasma Germany
- ProAnimalLife (PromoTool)
- Surface for Food
- VDE Verband der Elektronik

COOPERATIONS

- Agroscope, Zürich
- AJ Drexel Plasma Institute, Philadelphia
- Brno University of Technology, Czech Republic, Brno
- C3 e.V., Dresden
- Central European Institute of Technology (CEITEC), Brno
- CentraleSupélec, University Paris-Saclay, Paris
- Centre for Mathematical Plasma-Astrophysics, Leuven
- Centrum Wiskunde & Informatica, Amsterdam
- Charité Berlin, Berlin
- Chemnitz University of Technology, Chemnitz
- Chongqing University, China, Chongqing
- Christian-Albrechts-Universität zu Kiel, Kiel
- College of Electrical and Information Engineering, Hunan University, Changsha
- Comenius University in Bratislava, Slovakia, Bratislava
- Costa Rica institute of Technology, Cartago
- CSIRO Manufacturing, Lindfield
- Cytocentrics Bioscience GmbH, Köln
- Deutsche Zentralbibliothek für Wirtschaftswissenschaften (ZBW), Kiel
- DIL Deutsches Institut für Lebensmitteltechnologie e.V., Quakenbrück
- DLR - German Aerospace Center, Köln
- DLR-Institute of Networked Energy Systems, Oldenburg
- DST Diagnostische Systeme & Technologien GmbH, Schwerin
- Dutch Institute for Fundamental Energy Research (DIF-FER), Eindhoven
- EFDS - European Society of Thin Films, Dresden
- Eindhoven University of Technology TU/e, Eindhoven
- Empa, Swiss Federal Laboratories for Materials Science and Technology, Plasma & Coating Group, St.Gallen
- Euroimmun Medizinische Labordiagnostika AG, Lübeck
- Ferdinand-Braun-Institut, Leibniz-Institut für Höchstfrequenztechnik (FBH), Berlin
- Forschungsverbund Mecklenburg-Vorpommern e.V., Rostock
- Fraunhofer Institute for Applied Optics and Precision Engineering IOF, Jena
- Fraunhofer Institute for Electronic Nano Systems, Chemnitz
- Fraunhofer Institute for Environmental Safty and Energy Technology UMSICHT, Oberhausen
- Fraunhofer Institute for Manufacturing Technology and Advanced Materials IFAM, Bremen
- Fraunhofer Institute for Material and Beam Technology IWS, Dresden
- Fraunhofer Institute for Organic Electronics, Electron Beam and Plasma Technology FEP, Dresden
- Fraunhofer Institute for Surface Engineering and Thin Films IST, Braunschweig
- Fraunhofer Institute for Surface Engineering and Thin Films IST, DOC Dortmunder OberflächenCentrum GmbH, Dortmund
- Fraunhofer-Institut für Keramische Technologien und Systeme IKTS, Hermsdorf
- Fraunhofer-Research Institution for Large Structures in Production Engineering IGP, Rostock
- Fraznhofer Institut für keramische Technologien und Systeme IKTS, Dresden
- Friedrich Löffler Institut, Greifswald - Insel Riems
- Fudan University, China, Shanghai Shi
- Groupe des Couches Minces (GCM) and Department of Engineering Physics, Polytechnique Montreal, Montreal
- Helmholtz-Zentrum Rossendorf, Dresden

- Herz- und Diabeteszentrum NRW, Bad Oeynhausen
Universitätsklinik der Ruhr-Universität Bochum , Bad Oeynhausen
- Hochschule Bremen
- Hochschule für angewandte Wissenschaft und Kunst HAWK, Hildesheim/Holzminden/Göttingen
- Hochschule für Angewandte Wissenschaften Hamburg (HAW)
- Hochschule Neubrandenburg
- Hochschule Stralsund
- Holon Institute of Technology, Israel, Holon
- IHK Neubrandenburg, Neubrandenburg
- INM – Leibniz Institute for New Materials, Saarbrücken
- Innovations- und Bildungszentrum Hohen Luckow e.V., Hohen Luckow
- Innovent e.V., Jena
- INPLAS - Network of Competence Industrial Plasma Surface Technology, Braunschweig
- Institut für Bioprozess- und Analysenmesstechnik e.V. Rosenhof, Bad Heiligenstadt
- Institut für Energietechnik, Energieverfahrenstechnik und Umwandlungstechniken regenerativer Energien (EVUR), Berlin
- Institut für Werkzeugmaschinen und Fabrikbetrieb, TU Berlin
- Institut national de la recherche agronomique (INRA), Paris
- Institute for Solid State Physics and Optics, Wigner Research Centre for Physics, Budapest, Hungary
- Institute of High Current Electronics, Tomsk
- Institute of Plasma Physics of the Czech Academy of Science, Czech Republic, Praha
- Instituto de Astrofísica de Andalucía (IAA-CSIC), Granada
- Instituto de Plasmas e Fusão Nuclear, Lisboa
- Instituto Superior Técnico, Lisboa
- International Sakharov Environmental University, Belarus, Russia, Minsk
- Justus-Liebig Universität, Gießen
- Karlsruhe Institute of Technology, Karlsruhe
- Kaunas University of Technology, Lithuania, Kaunas
- Klinikum Karlsruhe
- KTH Royal Institute of Technology Stockholm, Stockholm
- Kwangwoon University, Seoul, South-Korea
- Laboratory on plasma and conversion of energy, Toulouse, France
- Leibniz Institut für Analytische Wissenschaften ISAS e.V., Dortmund
- Leibniz Institut für Astronomie (AIP), Potsdam
- Leibniz Institut für Festkörper- und Werkstoffforschung Dresden e.V. (IFW)
- Leibniz Institut für Informationsinfrastruktur (FIZ), Karlsruhe
- Leibniz Institut für Oberflächenmodifizierung e.V. (IOM), Leipzig
- Leibniz Institute for Baltic Sea Research (IOW), Rostock
- Leibniz Institute for Catalysis (LIKAT), Rostock
- Leibniz Institute for Farm Animal Biology (FBN), Dummerstorf
- Leibniz Institute of Photonic Technology (IPHT), Jena
- Leibniz-Institut für Agrartechnik und Bioökonomie e.V. (ATB), Potsdam
- Leibniz-Institut für Atmosphärenphysik e.V. (IAP), Kühlungsborn
- Leibniz-Institut für Experimentelle Virologie, Hamburg
- Leibniz-Institut für Werkstofforientierte Technologien (IWT), Bremen
- Maritime University of Szczecin, Poland

COOPERATIONS

- Masaryk University, Brno, Czech Republic
- Max-Planck-Institut für Eisenforschung GmbH, Düsseldorf
- Medical School of Panepistimio Thessalias, Larissa, Greece
- Menlo Systems GmbH, Martinsried
- Ministerium für Wirtschaft, Bau und Tourismus MV, Schwerin
- Nagoya University, Japan, Nagoya
- National Institute for Laser, Plasma and Radiation Physics, Bucharest, Romania
- National Institute of Standards & Technology (NIST), Gaithersburg, MD, USA
- National Technical University of Athens
- neoplas GmbH, Greifswald
- Neoplas med, Greifswald
- Nicolaus Copernicus University, Torun, Poland
- North Carolina State University, Raleigh
- Old Dominion University Norfolk, Virginia
- Paul-Drude-Institut für Festkörperelektronik (PDI), Berlin
- PBRC, Kwangwoon University, Seoul, Korea
- Peking University, China
- Plasma Advanced Research Center, University Iasi, Romania
- PlasmaMedic LTD, Israel, Givatayim
- Politecnico di Milano, Italy
- Preparatory Institute of Engineering Studies of Monastir
- PTB Braunschweig, Braunschweig
- Queensland University of Technology, Brisbane, Australia
- Research Center Borstel - Leibniz Lung Center, Sülfeld
- Riga Technical University, Latvia, Riga
- Rübig GmbH & Co KG, Wels, Austria
- Ruhr-Universität Bochum
- RWTH Aachen University
- Saarland University, Saarbrücken
- São Paulo State University (UNESP), São Paulo
- Schweißtechnische Lehr- und Versuchsanstalt Rostock (SLV)
- Sirona Dental Systems GmbH Bensheim
- Stadtwerke Netzgesellschaft mbH, Rostock
- Strahlenklinik des Universitätsklinikums Erlangen
- Szewalski Institute of Fluid Flow Machinery, Gdansk, Poland
- Taras Shevchenko National University of Kyiv
- Technical University of Denmark, Roskilde, Denmark
- Technische Universität Bergakademie Freiberg
- Technische Universität Berlin
- Technische Universität Braunschweig
- Technische Universität Dresden
- Technische Universität Hamburg, Institut für Chemische Reaktionstechnik, Hamburg
- Technische Universität Ilmenau
- Technological University Dublin, College of Sciences and Health, School of Food Science and Environmental Health, Dublin
- TH Brandenburg, Brandenburg an der Havel
- The hydrogen and fuel cell center ZBT GmbH, Duisburg
- TIB – Leibniz-Informationszentrum Technik und Naturwissenschaften und Universitätsbibliothek, Hannover
- Tomsk Polytechnic University, Tomsk
- Tsinghua University, Beijing Shi
- Umeå University, Umeå, Sweden

- Universidade de Lisboa
- Universidade Estadual de Londrina, Brasilien
- Universidade Estadual Paulista (UNESP), Guaratinguetá, São Paulo, Brazil
- Università degli Studi di Bari Aldo Moro, Bari, Italy
- Universität Rostock, Universitätsmedizin
- Universität Wien
- Universität zu Lübeck
- Universitätsklinikum des Saarlandes, Homburg
- Universitätsmedizin Essen
- Université d'Orléans, France
- Université de Lorraine, Nancy, France
- Université de Pau, France
- Université PARIS-SUD, Orsay
- University of Antwerp, Antwerp
- University of Applied Sciences and Arts, Göttingen
- University of Applied Sciences, Technology, Business and Design, Wismar
- University of Belgrade, Serbia, Belgrade
- University of Birmingham, UK
- University of Buenos Aires, Argentina
- University of Cambridge, UK
- University of Greifswald
- University of Greifswald, University Medicine
- University of Madeira, Funchal
- University of Malta, Msida
- University of Maryland (UMD), College Park, MD, USA
- University of Medicine and Pharmacy Lasi, Lasi
- University of Minnesota, Minneapolis, USA
- University of Monastir, National School of Engineering of Monastir
- University of Oxford, UK
- University of Pavia
- University of Purdue, West Lafayette, Indiana
- University of Reading, UK
- University of Rennes, France
- University of Rostock
- University of Sheffield
- University of Tartu, Estonia
- University of the Basque Country , Bilbao
- University of York
- University Sorbonne Paris, Villetaneuse, France
- Uppsala University, Sweden
- VTT Technical Research Centre of Finland, Espoo
- Wageningen University
- West Pomeranian University of Technology, Szczecin, Poland
- Wrocław University of Science and Technology, Wrocław, Polen
- Xi'an Jiaotong University, Xi'an
- ZAL Center of Applied Aeronautical Research, Hamburg
- Zentrum für Ernährung und Lebensmitteltechnologie gGmbH, Neubrandenburg



CONTRIBUTIONS TO EDITED VOLUMES 2022

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INVITED TALKS 2022

Ravandeh, M.: **Combination of cold atmospheric plasma and biomimetic membrane as a versatile toolbox in redox medicine**. Skin@Bath Network Symp., Bath/UK 2022

Baeva, M.; Hannig, M.; Methling, R.; Gött, G.; Gonzalez, D.: **Predictive capability and efficiency of 2D planar against 3D models of LV interrupters**. 31st Int. Conf. on Electrical Contacts (ICEC), Sapporo/Japan 2022

Becker, M. M.; Chaerony Siffa, I.: **Metadata schema and tools for research data management in plasma technology**. 48th Annual Plasma Physics Conference, Liverpool/UK 2022

Bekeschus, S.: **Medical Gas Plasma Technology – The Now and Future**. 14th ISPlasma, Nagoya/Japan 2022

Brandenburg, R.; Schiörlin, M.; Hosseini-Rad, R.; Schmidt, M.; Brüser, V.: **Dielectric Barrier Discharges for Gas Conversion: From Decontamination to Synthesis**. 18th Int. Conf. on Plasma Surface Engineering (PSE), Erfurt/Germany 2022

Clemen, R.; Miebach, L.; Wende, K.; Bekeschus, S.: **Gas Plasma Technology Augments Ovalbumin Immunogenicity and OT-II T Cell Activation Conferring Tumor Protection in Mice** 9th ICPM, Utrecht/Netherlands 2022

Kruth, A.: **Podiumsdiskussion Ammonia: a versatile hydrogen carrier**. European Hydrogen Week, Brussels/Belgium 2022

Kruth, A.: **CAMPFIRE Green Ammonia Technology Development**. hy-fcell, Stuttgart/Deutschland 2022

Kruth, A.: **Ammoniak als Schiffsantrieb**. DPG Frühjahrstagung - Arbeitskreis Energie, Erlangen/Deutschland 2022

Masur, K.: **Cold Plasma for accelerated healing of chronic wounds in diabetic patients**. 12th Int. Symp. on Plasma Bioscience (ISPB-12), Seoul/Korea 2022

Masur, K; Meister, M; Choi, Eun Ha; Hasse, S; von Woedtke, T: **Standardization in Plasma Medicine: From DIN Spec to IEC standards**. 12th Int. Symp. on Plasma Bioscience (ISPB-12), Seoul/Korea 2022

Masur, K; Meister, M; Choi, Eun Ha; Weltmann, K-D; von Woedtke, T: **Cold Plasma for Accelerated Healing of Chronic Wounds in Diabetic Patients**. 20th Int. Congr. on Plasma Physics, Gyeongju/Korea 2022

Masur, K; Shome, D; Schmidt, J; von Woedtke, T: **Wundtherapie mit Kaltem Plasma - vom Labor in die klinische Anwendung**. 3. WundD.A.CH Dreiländerkongress, Stuttgart/Deutschland 2022

Miebach, L.; Freund, E.; Wende, K.; Kersting, S.; von Woedtke, T.; Bekeschus, S. **Conductivity augments ROS and RNS delivery and tumor toxicity of an argon plasma jet.** 9th ICPM, Utrecht/Netherlands 2022

Schnabel, U.; Ell, A.; Morath, C.; Schlüter, O.; Bourke, P.; Ehlbeck, J.: **Plasma Treated Water: Scaling Efficacy from Bench to Pilot to Industry for Fresh Produce.** European Symposium on Food Safety, München/Deutschland 2022

Weltmann, K.-D.; v. Woedtke, T.; Kolb, J.F.; Brandenburg, R.; Gerling, T.; Bekeschus, S.; Bansemer, R.; Hahn, V.; Ehlbeck, J.; Brust, H.; Zocher, K.; Brüser, V.; Kruth A.; Clemen R.: **With Plasma from Medicine to Hydrogen.** Plasma Processing and Technology Int. Conf., Barcelona/Spain 2022

Wende, K.: **Is biomolecule oxidation by plasma-derived reactive species restricted to the gas-liquid interphase?** 49th Intern. Conf. on Plasma Science (ICOPS), Seattle/USA 2022

Wubs, J. R.: Macherius, U.; Weltmann, K.-D.; Lü, X.; Röben, B.; Biermann, K.; Schrottke, L.; Grahn, H. T.; van Helden, J. H.: **Terahertz Spectroscopy for Measurements of Electron and Atomic Oxygen Densities in Plasma** 7th Int. Conf. on Field Laser Applications in Industry and Research (FLAIR), Aix-Les-Baines/France 2022

INVITED TALKS2023

Gerling, T.: **Design of an Automatic Contactless Wound Size Measurement System with Deep Learning and Computer Cision.** 6. Nürnberger Wundkongress, Nürnberg/Deutschland 2023

Becker, M. M.; Brandenburg, R.; Hoder, T.; Höft, H.; Jovanovic, A. P.; Loffhagen, D.: **Modelling and analysis of single-filament dielectric barrier discharges at atmospheric pressure.** DPG-Frühjahrstagung SMuK, Dresden/Deutschland 2023

Becker, M. M.; Brandenburg, R.; Hoder, T.; Höft, H.; Jovanovic, A. P.; Loffhagen, D.: **Standards and tools for modelling and data-driven analysis of technological plasmas.** 20. Fachtagung Plasmatechnologie, Bochum/Deutschland 2023

Bekeschus, S.: **Gas Plasma Technology in Medical Care.** 20. Fachtagung Plasmatechnologie, Bochum/Deutschland 2023

Bekeschus, S.: **Plasma treatment of cancers – ablation vs. Immunotherapy.** 8th Intern. Workshop on Plasma for Cancer Treatment (IWPCT), Raliegh/USA 2023

Brandenburg, R.; Pipa, A.V.; Hosseini Rad, R.; Schiörlin, M.; Bröcker, L.; Klages, C.-P.: **Electrical characterization of barrier discharges: Linking fundamentals and applications.** 3rd Plasma Thin Film International Union Meeting (PLATHINIUM), Antibes/France 2023

Brandenburg, R.; Schiörlin, M.; Brüser, V.; Adrianto, D.; Mahdikia, H.; Hosseini Rad, R.: **CO₂ Splitting in Dielectric Barrier Discharges: Prospects to Increase CO Formation.** 785. WE-Heraeus Seminar on Non-Thermal Plasmas for Sustainable Chemistry, Bad Honnef/Germany 2023

Brüser, V.; Mousazadeh Borghei, S.; Adrianto, D.; Kolb, J. F.; Brandenburg, R.: **Plasma-assisted catalytic processes for hydrogen storage and production.** 13th Asian-European Int. Conf. on Plasma Surface Engineering, Busan/South Korea 2023

Brust, H.: **Plasmaanwendungen für die Landwirtschaft: Potenziale und Herausforderungen.** 43. ak-adp Workshop, Leipzig/Germany 2023

Brust, H.: **Plasmaanwendungen für die Landwirtschaft: Potenziale und Herausforderungen.** 43. ak-adp Workshop, Leipzig/Germany 2023

Brust, H.; Bousselmi, S.; Wagner, R.; Seipke, E.S.: **Effects of plasma treated water on narrow-leaved lupin (*Lupinus angustifolius* L.) under abiotic stress.** 4th Intern. Workshop on Plasma Agriculture (IWOPA), Seoul/South Korea 2023

Clemen, R.; Bekeschus, S.: **Gas Plasma Technology in Medical Care.** Int. Conf. on Research and Applications of Plasmas (PLASMA2023), Warsaw/Poland 2023

Gortschakow, S.: **Optical diagnostics of switching vacuum arcs.** 30th ISDEIV, Okinawa/JP, 2023

Gortschakow, S.: **Influence of electrode surface evolution on the properties of high-current vacuum arcs in switching applications.** 24th Symp. on Physics of Switching Arc, Nove Mesto na Morave/Czech Republic 2023

Hempel, F.: **Physikalische Plasmen - ein wertvolles Werkzeug zur gezielten Modifizierung der Oberflächenegenschaften von Implantaten.** EFDS-Workshop "Implantate – Wenn die Antwort in der Schicht steckt", Tuttlingen/Germany 2023

Höft, H.; Huiskamp, T.; Jovanovic, A. P.; Loffhagen, D.; Becker, M.M.; Mattern, P.; Gerling, T.: **Absolute ion density measurement (MAID) by evaluating ion acoustic waves in the plasma – an approach via external excitation.** 2nd Annual meeting of COST Action PlasTHER, Bologna/Italy 2023

Höft, H.; Kettlitz, M.; Schmidt, M.; Becker, M.M.; Brandenburg, R.: **Understanding single-filament barrier discharges as a keystone for optimised multi-filament reactors.** 20. Fachtagung Plasmatechnologie, Bochum/Deutschland 2023

Kolb, J. F.; Brüser, V.; Borghei, S. M.; Hahn, V.; Schneider, M.; Rataj, R.; Weltmann, K. D.: **Chemical Transformation by Atmospheric Pressure Discharges in Air with the Addition of Water.** 23rd Int. Conf. on Gas Discharges and their Applications, Greifswald/Germany 2023

Kolb, J. F.; Brust, H.; Bansemer, R.; Wannicke, N.; Weltmann, K. D.: **Plasma Agriculture – from Laboratory to Field.** 4th Intern. Workshop on Plasma Agriculture (IWOPA), Seoul/South Korea 2023

Kolb, J. F.; Schneider, M.; Brust, H.; Rataj, R.; Wannicke, N.; Brüser, V.; Weltmann, K. D.: **Plasma Treatment of Water for Agricultural Production.** Global Plasma Forum, Aomori/Japan 2023

Kruth, A.; Wartmann, J.: **Praxisbeispiel zur Regionalentwicklung: „Synergien für die Entwicklung von Technologiefeldern am Beispiel Ammoniak- und Wasserstoffforschung“ - Emissionsfreie Energie in der Region Nord-Ost“.** IX. Sitzung der Bund-Länder-AG SynBLAG, Berlin/Deutschland 2023

Kruth, A.; Wartmann, J.: **CAMPFIRE Partner Alliance for Implementation of Green Ammonia Technologies.** Energetech 2023, Paris/France

Kruth, A.; Wartmann, J.: **Grüne Ammoniak Technologien für Energiesicherheit, Klimaschutz und Wirtschaftswachstum.** Regionalkonferenz Gemeinsam.Nachhaltig.Regional, Rostock/Deutschland 2023

Kruth, A.; Wartmann, J.: **CAMPFIRE Partner Alliance for Implementation of Green Ammonia Technologies.** H₂ Forum im ECC, Berlin/Deutschland 2023

Kruth, A.: **Plasma-gestützte Erzeugung von Materialien für die Wasserstofftechnologie.** INPLAS-AG Neuartige Plasmaquellen und -prozesse, 31.Treffen, Salzgitter/Deutschland 2023

Kruth, A.: **Germany in Focus – opportunities für green and low-carbon hydrogen in the country.** Hydrogen Dialogue Latin America, Sao Paulo/Brazil 2023

Kruth, A.: **The role of ammonia as a hydrogen carrier.** World Hydrogen 2023, Rotterdam/The Netherlands 2023

Kruth, A.: **Praxisbeispiel zur Regionalentwicklung „Synergien für die Entwicklung von Technologiefeldern am Beispiel Ammoniak- und Wasserstoffforschung - Emis-**

sionsfreie Energie in der Region Nord-Ost“. Synergien nutzen: Horizont Europa und Strukturfonds, Essen/Deutschland 2023

Kruth, A.: **CAMPFIRE Partner Alliance for Implementation of Green Ammonia Technologies.** HY-5: Europe's Future Leading Green Hydrogen Region, Rostock-Laage/Deutschland 2023

Kruth, A.: **Panel II: Industrie „Nutzung von grünem Wasserstoff“ – unterstützt von thyssenkrupp Steel Europe.** Hy.Summit.Rhein.Ruhr, Duisburg/Deutschland 2023

Kruth, A.: **The Potential of Green Ammonia in Developing and Emerging Countries.** The Potential of Green Ammonia in Developing and Emerging Countries, Berlin/Deutschland 2023

Rettke, D.; Barillas-Mora, L.: **SurfAP3®: A Desktop Plasma Printing Technology for Micrometer-Scale Surface Treatment Targeted at Biomedical Applications.** V2023-Workshop "Coatings for Biomedical Applications", Dresden/Germany 2023

Sadiek, I.; Lang, N.; van Helden, J. H.: **Mid-infrared frequency comb spectroscopy of plasmas.** 20th LAPD, Kyoto/Japan 2023

Schnabel, U.; Stachowiak, J.; Ehlbeck, J.: **Innovative washing & disinfection of fresh-cut lettuce.** KRONEN Customer Day, Kehl/Germany, 2023

Uhrlandt, D.: **Electric models of arcs in different applications.** 24th Symp. on Physics of Switching Arc, Nove Mesto na Morave/Czech Republic 2023

Uhrlandt, D.: **Experimental studies of arcs in hydrogen containing gases.** Munich Hydrogen Symposium, München-Garching/Germany 2023

Woedtke, T.: **Cold atmospheric plasma applications in medicine.** 49th Annual Plasma Physics Conference, Oxford/UK 2023

van Helden, J. H.; Wubs, J. R.; Macherius, U.; Lü, X.; Röben, B.; Biermann, K.; Schrottke, L.; Grahn, H.T.; Weltmann, K.-D.: **Plasma Diagnostics with THz Lasers.** Optica Sensing Congress, München/Deutschland 2023

Wannicke, N.; Brust, H.: **Potential der Saatgutbehandlung mit physikalischem Kaltplasma (CAP) zur Saatguthygiene und Biostimulanz.** 134. VDLUFA-Kongress - Klimaanpassung und Ernährungssicherheit - Herausforderungen für die Landwirtschaft, Freising/Germany 2023

Weltmann K.-D.; von Woedtke T.: **Plasma Medicine Knowledge and Technology Transfer FROM IDEA TO PRODUCT.** Electron-driven processes, Symposium in Honor of Kurt H. Becker, Brooklyn/USA 2023

Weltmann, K.-D.; von Woedtke, Th.; Kolb, J.F.; Gerling, T.; Kruth, A.: **Low temperature plasma - About a Hidden Champion or a Silent Revolution.** DPG-Frühjahrstagung SMuK, Dresden/Deutschland 2023

TALKS 2022

Methling, R.; Gonzalez, D.; Schmausser, S.; Kellermann, M.; Ehrhardt, A.: **Investigation of Post Arc Radiating Behaviour of a Spark Gap for DC Protection.** 31st Int. Conf. on Electrical Contacts (ICEC), Sapporo/Japan 2022

Baeva, B.; Zhu, T.; Benilov, M.; Testrich, H.; Kewitz, T.; Methling, R.; Wallis, J.; Foest, R.: **Plasma spraying related modelling and experimental studies .** Plasma Processing and Technology Int. Conf., Barcelona/Spain 2022

Balazinski, M.; Hahn, V.; Kolb, J.F.: **Decontamination of water using pulsed electric fields (PEF) and plasma for aquaculture.** 8th PEF School on Pulsed Electric Field Appl. in Food and Biotechn., Compiegne/France 2022

Balazinski, M.; Schmidt, M.; Arndt, G-M.; Weltmann, K.-D.; Kolb, J.F.; Hahn, V. **Physical Plasma as an efficient and sustainable disinfection technology in recirculating aquaculture systems.** Aquaculture Europe 2022, Rimini/Italy 2022

Barillas-Mora, L.: **SurfAP3® Direct Writing Micro Plasma Printing for Localized Surface Functionalization Aimed at Biosensing and Microfluidic Applications.** Micro and Nano Engineering (MNE) Eurosensors, Leuven/Belgien 2022

Barillas-Mora, L.: **SurfAP3® – Direct Writing Micro Plasma Printing for Localized Surface Modification of Biosensors and Microfluidic Devices.** 11th Int. Workshop on Microplasmas, Raleigh/USA 2022

Barillas-Mora, L.: **SurfAP3® – Plasma Printing for Local Surface Modification of Biosensors and Microfluidics.** 11th Workshop of Chemical and Biological Micro Laboratory Technology, Ilmenau/Germany 2022

Becker, M. M.; Chaerony Siffa, I.; Gerling, T.; Höft, H.; Jovanovic, A. P.; Kusyn, L.; Loffhagen, D.; Stankov, M. N.; Hoder, T.: **Combining modelling and experiment for advanced plasma diagnostics.** 17th Hakone, Kerkrade/Netherlands, 2022

Bekeschus, S. **Medical gas plasma as an innovative technology for therapy and immunomodulation in skin cancer.** 16th Int. Symposium "Tumor Immunology meets Oncology XIV", Halle/Germany 2022

Bekeschus, S.; Evert, K.; Kocher, T.; Schindler, A.; Müller, M.; Pink, C.; Holtfreter, B.; Schmidt, A.; Dombrowski, F.; Schubert, A.; von Woedtke, T.; Rupf, S.; Calvisi, D.; Jablonowski, L. **Repeated exposure of the oral mucosa over 12 months with cold plasma is not carcinogenic in mice.** 9th ICPM, Utrecht/Netherlands 2022

Bekeschus, S.; Miebach, L.; Berner, J.; Freund, E.; Burchardt, M.; Gelbrich, N. **Medical gas plasma augments bladder cancer cell toxicity and immunogenicity in preclinical models and patient-derived tumor tissues.** 9th ICPM, Utrecht/Netherlands 2022

Bekeschus, S.; Singer, D.; Wende, K.; Schmidt, A. **Expression signatures associated with oxidative stress sensitivity in 30 human cancer cell lines.** Redox Biology Congress, Ghent/Belgium, 2022

Bousselmi, S.; Bretschneider, E.S.; Wagner, R.; Pan, Y.; Horn, S.; Brust, H.: **Effects of plasma treated water on seed germination and growth of blue lupine (*Lupinus angustifolius* L.) plants under abiotic stress.** 9th Central European Symp. on Plasma Chemistry (CESPC), Strebske Plesko/Slovakia 2022

Brandenburg, R; Hink, R. **Zum Potential von Plasmatechnologien zur Verwertung von biogenem Kohlendioxid - Ansätze im WIR!-Bündnis biogiiV.** 29. REGWA Energie-Symposium, Stralsund/Deutschland 2022

Chaerony Siffa, I.; Masur, K.; Eschenburg, C.; Emmert, S.; Gerling, T.: **"AmbuPlas" - development of a mobile sensory device (MSD) to trace treatment conditions for various medical plasma devices.** 9th ICPM, Utrecht/Netherlands 2022

Collantes Jiménez, P.; Sievers, G. W.; Quade, A.; Brüser, V.; Arenz, M.: **Bridging the gap between lab and application: A novel Porous Transport Electrode three-electrode set-up for degradation studies under realistic current densities of magnetron sputtered Ir-based catalys.** GDCh Electrochemistry 2022, Berlin/Deutschland 2022

Collantes Jiménez, P.; Wiberg, G.K.H.; Arenz, M.; Sievers, G.W.; Brüser, V.: **Bridging the gap between lab and application: A novel Porous Transport Electrode three-electrode set-up for degradation studies under realistic current densities of magnetron sputtered Ir-based catalys.** Symp. on Insights into Gas Diffusion Electrodes: From Fundamentals to Industrial Applications, Magdeburg/Deutschland 2022

Ehlbeck, J.; Stachowiak, J.; Andrasch, M.; Handorf, O.; Schnabel, U.: **Plasma treated water for application in food science.** 41. ak-adp Workshop - Atmosphärendruckplasma für hygienisch sensible Bereiche, Hannover/Deutschland 2022

Fischer, M.; Schoon, J.; Bekeschus, S.; Wassilew, G. **Der Einfluss von klinisch zertifiziertem Gasplasma auf das Sekretom und das osteogene Potential von mesenchymalen Stammzellen einer endoprothetischen Patientenkollektiv.** Deutscher Kongress für Orthopädie und Unfallchirurgie, Berlin/Deutschland 2022

Gelbrich, N.; Miebach, L.; Burchardt, M.; Zimmermann, U.; Bekeschus, S. **Antineoplastische Effekte in humanen Harnblasenkrebszellen und in von Patienten stammendem Tumorgewebe nach einer Behandlung mit medizinischem Gasplasma.** 13. Symposium Urologische Forschung der DGU e.V., Erlangen/Deutschland 2022

Gelbrich, N.; Miebach, L.; Burchardt, M.; Zimmermann, U.; Bekeschus, S. **Medizinisches Gasplasma in der Uroonkologie – Erfolgversprechende Therapieoption bei der Behandlung von Harnblasenkrebs.** 74. Kongress der Deutschen Gesellschaft für Urologie, Hamburg/Deutschland 2022

Gerling, T.; Masur, K.; von Woedtke, T.; Weltmann, K.-D.: **Kaltplasma in der Wundbehandlung: Technische Voraussetzungen.** Wundsymposium 'Wunden und Venen im Winter', Rostock/Deutschland 2022

Gerling, T.; Vilardell Scholten, L.; Hahn, V.; Hasse, S.; Mattern, P.; Weltmann, K.-D.; von Woedtke, T.; Eberhard, C.; Matthes, R.; Jablonowski, L.; Kocher, T.: **Development, qualification and preliminary certification of a dental plasma device for a multicenter clinical study.** 9th ICPM, Utrecht/Netherlands 2022

Gerling, T.; Vilardell Scholten, L.; Hahn, V.; Hasse, S.; Mattern, P.; Weltmann, K.-D.; von Woedtke, T.; Eberhard, C.; Matthes, R.; Jablonowski, L.; Kocher, T.: **Development, qualification and preliminary certification of a dental plasma device for a multicenter clinical study.** 9th ICPM, Utrecht/Netherlands 2022

Gonzalez, D.; Methling, R.; Gortschakow, S.; Koepf, H.; Steegmueller, P.; Holbe, S.: **Investigation of the Plasma of a DC hybrid-switch model at beginning of contact separation.** 31st Int. Conf. on Electrical Contacts (ICEC), Sapporo/Japan 2022

Hadian, K.; Rataj, R.; Jablonowski, H.; Bansemer, R.; Bekeschus, S.; Brandenburg, R.; Hahn, V.; Mrochen, D. M.; von Woedtke, T.; Gerling, T.: **Electrical and optical investigation of the long term operation of an endoscopic plasma device.** 9th ICPM, Utrecht/Netherlands 2022

Hahn, V.; Balazinski, M.; Schmidt, M.; Weltmann, K.-D.; von Woedtke, T.; Kolb, J.: **Physical plasma for decontamination in aquaculture.** Aquaculture Europe 2022, Rimini/Italy 2022

Hasse, S.: **Investigations on microbiome and proteome in chronic wound exudates under plasma treatment.** 9th ICPM, Utrecht/Netherlands 2022

Hasse, S.; Masur, K. **Kaltplasmaanwendungen bei diabetischen Fußwunden.** Wundsymposium des Wundnetz Berlin-Brandenburg e.V., Berlin/Deutschland 2022

Hempel, F.: **Aktuelle Trends für die Anwendung physikalischer Plasmen zur Modifikation von Oberflächen im Life Science Bereich.** 16. Thementage Grenz- und Oberflächentechnik (ThGOT), Zeulenroda/Deutschland 2022

Hink, R.; Uhrlandt, D. **biogeniV Bündnis Vorstellung – neue Verfahren und Technologien zur Verwertung biogener Reststoffe im östlichen MV.** 16. Rostocker Bioenergieforum, Rostock/Deutschland 2022

Hinzke, T.; Zühlke, D.; Schneider, D.; Hahn, V.; Stressmann, F.; Premke, K.; Kolb, J. F.; Daniel, R.; Riedel, K.: **Sewage treatment plants as hotspots of critical antibiotics resistances - and how to tackle this health threat.** One Health Conference (OHC), Virtual Event/Internet 2022

Höft, H.; Wubs, J. R.; Kettlitz, M.; Becker, M.M.; Weltmann, K.-D.: **Investigations on the impact of electrode proximity on streamer breakdown and development of pulsed DBDs.** DPG Frühjahrstagung Plasmaphysik, Virtual Event/Internet 2022

Hosseini Rad, R.; Schiörlin, M.; Brüser, V.; Brandenburg, R.: **CO₂ conversion in barrier discharges with and without packed bed filling at elevated pressures.** DPG Frühjahrstagung Plasmaphysik, Virtual Event/Internet 2022

Jovanovic, A. P.; Höft, H.; Loffhagen, D.; Becker, M. M.: **Modelling of streamer inception in pulsed-driven dielectric barrier discharges at atmospheric pressure.** DPG Frühjahrstagung Plasmaphysik, Virtual Event/Internet 2022

Käufer, F.; Maess, R.; Kahlert, H.; Kruth, A.: **Synthesis of catalytically active filter materials via plasma-mediated method for application in electro-fenton process for degradation of pharmaceuticals, online, 2022.** 13th Ed. of Int. Conf. on Catalysis, Chemical Engineering and Technology, Orlando/USA 2022

Klose, S.-J.; van Helden, J. H.: **The spatial distribution of species in an atmospheric pressure plasma jet investigated by cw cavity ring-down spectroscopy.** 14th Cavity Enhanced Spectroscopy Meeting (CES), Lecco/Italy 2022

Krüger, T: **Surface and material modification to influence the adhesion of plasma sprayed coatings.** Material Research Society (MRS) Fall Meeting & Exhibit, Boston/USA 2022

Lang, N.; Ellis, J.; Köpp, D.; van Helden, J. H.: **Clarification of the production mechanism of ammonia in a hydrogen plasma with parts per million nitrogen .** Frontiers in Low Temperature Plasma Diagnostics XIV, Levico Terme/Italy 2022

Mahdikia, H.; Brüser, V.; Brandenburg, R.: **CO₂ conversion in a barrier corona discharge at elevated pressures.** DPG Frühjahrstagung Plasmaphysik, Virtual Event/Internet 2022

Masur, K.; **Plasmamedizin vom Labor in die Klinik.** Wundsymposium 'Wunden und Venen im Winter', Rostock/Deutschland 2022

Masur, K: **Kaltplasma - Bench to Bedside; PALM Wundsymposium 'Wunden und Venen im Winter', Rostock/Deutschland 2022**

Masur, K; Meister, M; Choi, Eun Ha; Hasse, S; von Woedtke, T: **Standardization in Plasma Medicine: From DIN Spec to IEC standards.** 9th ICPM, Utrecht/Netherlands 2022

Masur, K; Meister, M; Peters, K; von Woedtke, T: **Plasma modulation of human progenitor cells.** 9th ICPM, Utrecht/Netherlands 2022

Masur, Kai **Plasmatherapie als alternativer Ansatz in der Wundversorgung.** Wundsymposium des Wundnetz Berlin-Brandenburg e.V., Berlin/Deutschland 2022

Mewafy, B.; Ravkina, O.; Arias-Serrano, B.; Wallis, J.; Rohloff, M.; Silva, J.; Kircheisen, R.; Kriegel, R.; Wartmann, J.; Kruth, A.: **Ammonia membrane reactor based on mixed-conducting thin-film oxygen membranes for optimised processing of ammonia as a carbon-free maritime fuel, Honolulu/USA, 2022.** Material Research Society (MRS) Spring Meeting & Honolulu, Hawaii/USA 2022

Mewafy, B.; Ravkina, O.; Arias-Serrano, B.; Wallis, J.; Rohloff, M.; Silva, J.; Kircheisen, R.; Kriegel, R.; Wartmann, J.; Kruth, A.: **Asymmetric Ba0.5Sr0.5Co0.8Fe0.2O3-d Membrane for Oxygen Permeation: Synergetic Fabrication By Magnetron Sputtering Deposition and Selective Laser Annealing, Atlanta/USA, 2022.** 242th ECS Meeting, Atlanta/USA 2022

Minkus, L.; Wende, K.: **Formation of Lipid Peroxidation Products by Gas Plasmas - Translation from the Liposome Model to Human Platelets.** 9th ICPM, Utrecht/Netherlands 2022

Mousazadeh Borghei, S.; Brüser, V.; Kolb, J. F.: **Splitting of CO₂ by a nanosecond-pulsed dielectric barrier discharge.** 5th Int. Symp. on Plasma for Catalysis and Energy Materials, Liverpool/UK 2022

Mousazadeh Borghei, S.; Brüser, V.; Kolb, J. F.: **CO₂ dissociation by a nanosecond pulsed dielectric barrier discharge.** DPG Frühjahrstagung Plasmaphysik, Virtual Event/Internet 2022

Nasri, Zahra **The impact of oxidative stress on the barrier properties of lipid bilayers.** 9th ICPM, Utrecht/Netherlands 2022

Naumann, A.: **Vorstellung der Aktivitäten des HyCore Clusters.** 29. REGWA Energie-Symposium, Stralsund/Deutschland 2022

Nishime, T.M.C.; Werner, J.; Horn, S.; Wannicke, N.; Weltmann, K.-D.; Brust, H.: **Influence of the reactor configuration on the treatment of rapeseed using a conical corona reactor.** 9th Central European Symp. on Plasma Chemistry (CESPC), Strebske Plesko/Slovakia 2022

Ravandeh, M.: **Protein corona formation and characterization of environmentally relevant microplastics generated by sonication.** Microplastics 2022, Ascona/Switzerland 2022

Rohloff, M.; Levien, M.; Krüger, T.; Sievers, G.; Wetegrove, M.; Kruth, A.: **Plasmaforschung für den Treibstoff von morgen, Bielefeld/Deutschland, 2022.** Plasma Germany Herbstsitzung, Steinhagen/Deutschland 2022

Rohloff, M.; Lindemann, U.; Albrecht, A.; Quade, Kruth, A.; A.; Prabhakar, M.; Rohwerder, M.; Scheu, C.; Kapp, J.; Lukassek, V.: **Challenges in Plasma-Based Synthesis of MAX-Phase Anti-Corrosion Coatings for Metallic Bipolar Plates, Boston/USA, 2022.** Material Research Society (MRS) Fall Meeting & Exhibit, Boston/USA 2022

Rojas, C.; Quarz, P.; Garcia, V.; Kapp, J.; Käufer, F.; Lukassek, V.; Scharfer, P.; Wartmann, J.; Schabel, W.; Kruth, A.: **Graphene Suspension by a new plasma-in-liquid process for thin film coatings of polymer-membranes for fuel cell application, Barcelona/Spanien, 2022 .** Plasma Processing and Technology Int. Conf., Barcelona/Spain 2022

Sadiek, I.; Lang, N.; van Helden, J. H.: **Mid-infrared Optical Frequency Comb Spectroscopy for Plasma Diagnostics.** Frontiers in Low Temperature Plasma Diagnostics XIV, Levico Terme/Italy 2022

Sadiek, I.; Lang, N.; van Helden, J. H.: **Mode-resolved Mid-Infrared Optical Frequency Comb Spectroscopy Using an Air-spaced VIPA without Optical Cavity Filtering .** 14th Cavity Enhanced Spectroscopy Meeting (CES), Lecco/Italy 2022

Sadiek, I.; Lang, N.; van Helden, J. H.: **An Air-spaced Virtually Imaged Phased Array Spectrometer Based on a Mid-Infrared Optical Frequency Comb.** OSA Optical Sensors and Sensing Congress, Virtual Event/Internet 2022

Sadiek, I.; Lang, N.; van Helden, J. H.: **A new broadband high-resolution spectrometer based on a mid-infrared frequency comb for plasma diagnostic.** Frontiers in Low Temperature Plasma Diagnostics XIV, Levico Terme/Italy 2022

Schmidt, M.; Hahn, V.; Rataj, R.; Hoffmann, U.; Skowski, H.; Bekeschus, S.; von Woedtke, Th.: **Non-thermal plasma for generation of antimicrobial aerosol.** 9th Central European Symp. on Plasma Chemistry (CESPC), Strebske Plesco/Slovakia 2022

Schmidt, M.; Kettlitz, M.; Kolb, J. F.: **Enhanced extraction of methyl ethyl ketone from a gas stream.** 12th Int. Symp. on Non-Thermal/Thermal Plasma for Pollution Control & Sustainable Energy (ISNTP-12), Hokkaido/Japan 2022

Schnabel, U.; Stachowiak, J.; Winter, H.; Ehlbeck, J.: **Non-thermal Plasma for Fresh Produce: Scaling Efficacy from Bench to Prototype and Industry for gaseous and liquid applications.** EFFoST/IFT-NPD Workshop on Non-thermal Processing of Foods, Dublin/Ireland 2022

Schwefel, K.; Malinverno, M.; Pilz, R.A.; Skowronek, D.; Leopoldi, A.; Biedenweg, D.; Bekeschus, S.; Penninger, J.M.; Dejana, E.; Felbor, U.; Rath, M. **Tumor-like proliferation of CCM3 knockout endothelial cells in co-culture with wild-type cells.** 12th Int. Kloster Seeon Meeting 'Angiogenesis', Seeon-Seebrück/Germany 2022

Uhrlandt, D.: **Entwicklung eines innovativen Systems für druckneutrale Hochspannungsanlagen unter Wasser .** 2. CO₂-Win Statuskonferenz des BMBF, Berlin/Deutschland 2022

Uhrlandt, D.: **Neue Verfahren und Technologien zur Verwertung biogener Reststoffe im östlichen MV .** 16. Rostocker Bioenergieforum, Rostock/Deutschland 2022

Wende, K.: **Biomolecule oxidation by CAP derived species – a general concept in biomedical plasma applications.** 9th Central European Symp. on Plasma Chemistry (CESPC), Strebske Plesco/Slovakia 2022

Wende, K.: **Biomolecule oxidation by gas phase species and the role of the gas-liquid interphase.** 17th Hakone, Kerkrade/Netherlands, 2022

Wende, K.: **Plasma-driven liquid chemistry .** COST ACTION PlasTHER Working Group 1 workshop, Virtual Event/Internet 2022

Wende, K.: **Protective role of sphingomyelin in eye lens membrane against oxidative stress during aging.** 24th Int. Conf. on Oxidative Stress Reduction, Paris/France 2022

Wende, Kristian **Relevance and limitation of plasma-driven protein oxidation in model and clinical application.** 9th ICPM, Utrecht/Netherlands 2022

Wetegrove, M.; Rohloff, M.; Lindemann, U.; Quade, A.; Román-Silva, J.; Kruth, A.: **Cathodic plasma electrolytic deposition of an aluminium oxide based hydrogen permeation barrier,** Barcelona/Spanien, 2022. Plasma Processing and Technology Int. Conf., Barcelona/Spain 2022

Wolff, C.; Singer, D.; Brito, W.A.S.; Saadati, F.; Berner, J.; Wende, K.; Schmidt, A.; Bekeschus, S. **The effect of microplastic particles on cells of the adaptive and innate immune system.** Microplastics2022, Ascona/Switzerland 2022

Wolff, C.; Singer, D.; Brito, W.A.S.; Saadati, F.; Berner, J.; Wende, K.; Schmidt, A.; Bekeschus, S. **The effect of microplastic particles on cells of the adaptive and innate immune system.** Microplastics2022, Ascona/Switzerland 2022

Wubs, J. R.: Macherius, U.; Weltmann, K.-D.; Lü, X.; Röben, B.; Biermann, K.; Schrottke, L.; Grahn, H. T.; van Helden, J. H.: **Terahertz Spectroscopy for Measurements of Atomic Oxygen Densities.** Gordon Res. Conf. Plasma Processing Sci., Andover/USA 2022

Wubs, J. R.: Macherius, U.; Weltmann, K.-D.; van Helden, J. H.: **Terahertz Spectroscopy for Measurements of Electron and Atomic Oxygen Densities.** Frontiers in Low Temperature Plasma Diagnostics XIV, Levico Terme/Italy 2022

Wubs, J. R.: Macherius, U.; Weltmann, K.-D.; van Helden, J. H.: **High-Resolution Terahertz Spectroscopy with Quantum-Cascade Lasers for Atomic Oxygen Density Measurements.** DPG Frühjahrstagung Plasmaphysik, Virtual Event/Internet 2022

Yao, Y.; Schnabel, U.; Stachowiak, Ehlbeck, J.: **Optimization and upscaling of non-thermal atmospheric plasma for decontamination of (a)biotic surfaces.** PROTECT/TRANSIT symposium - Food Sustainability & Safety in a Changing Climate, Dublin/Ireland 2022

Zocher, K.: **Scaling microalgal biomass extraction for industrial application.** 4th World Congr. on Electroporation and Pulsed Electric Fields in Biology, Medicine and Food & Environmental Technologies, Copenhagen/Denmark 2022

TALKS 2023

Augstein; P.: **Q-SCORE: A COMPOSITE METRIC FOR EVALUATION OF SHORT-TERM QUALITY OF GLYCEMIC CONTROL** 16th International Conference on Advanced Technologies & Treatments for Diabetes (ATTD), Berlin/Germany 2023

Adrianto, D.; Schiörlin, M.; Brüser, V.; Brandenburg, R.; Grumann, S.: **CO₂ splitting in 3D-printed barrier discharge reactors** DPG-Frühjahrstagung SMuK, Dresden/Deutschland 2023

Ahmadi, M.; Wagner, R.; Mattern, P.; Plathe, N.; Bekeschus, S.; Becker, M.M.; Weidtkamp-Peters, S.: **Towards multimodal data linking for bioimaging in plasma medicine** Data Stewardship goes Germany, Dresden/Germany 2023

An, S.: **Process Monitoring during Plasma Electrolytic Polishing (PEP) of WC-Co Based Cemented Carbide** 13th Asian-European Int. Conf. on Plasma Surface Engineering, Busan/South Korea 2023

An, S.: **Spatio-temporal characterization of gaseous layer development during plasma electrolytic polishing**, XXVII. Erfahrungsaustausch Oberflächentechnologie und Ionenstrahlprozesse, Mühlleithen, 2023 27. Erfahrungsaustausch Oberflächentechnologie, Mühlleithen/Germany 2023

Baeva, M. **Simulation of the Arc Motion in Low-Voltage Surge Protection Devices**. Comsol Conference, Munich/Germany 2023

Baeva, M. **Radiative heat transfer in models of dc arc plasma**. 24th Symp. on Physics of Switching Arc, Nove Mesto na Morave/Czech Republic 2023

Baeva, M.; Cressault, Y.; Kloc, P.: **Self-consistent access to radiative heat transfer in arc plasma models** 23rd Int. Conf. on Gas Discharges and their Applications, Greifswald/Germany 2023

Baeva, M.; Hannig, M.; Ehrhardt, A.; Methling, R.; Gött, G.; Gonzalez, D.: **Modelling studies and diagnostics of air arc plasma in LV surge protection devices** 23rd Int. Conf. on Gas Discharges and their Applications, Greifswald/Germany 2023

Baeva, M.; Zhu, T.; Testrich, H.; Foest, R.: **Simulation and experimental studies for plasma spraying applications** 25th Int. Symp. on Plasma Chemistry (ISPC), Kyoto/Japan 2023

Balazinski, M.; **Cold atmospheric plasma and pulsed electric fields as decontamination technologies for recirculating aquaculture systems**. Aquaculture Europe 2023, Wien/Austria 2023

Barillas-Mora, L.: **Mikro-APPS: Entwicklung und Transfer einer Mikro-Atmosphärendruck-Plasmaquelle (μAPPS) für die hochauflösende Behandlung von Oberflächen und die Mikrotechnik DATIpilot-Roadshow**, by BMBF (application for DATIpilot – Promoting & Learning for Innovation and Transfer), Rostock/Germany 2023

Barillas-Mora, L.: **Precision Plasma-Assisted Additive Manufacturing for the Fabrication of Multi-Material ELMs** DFG Workshop Priority Programme "Engineered Living Materials with Adaptive Functions" (SPP 2451), Saarbrücken/Germany 2023

Barillas-Mora, L.: **SurfAP3®: A Flexible Plasma-based Technology for Thin-film Printed Biosensors and Micro-fabrication** 33st Anniversary World Congress on Biosensors, Busan/South Korea 2023

Barillas-Mora, L.: **MicroQosmos: A True Desktop Solution for Maskless and Precise Surface Functionalization Using Atmospheric-Pressure Microplasmas and SurfAP3® Technology** 43. ak-adp Workshop, Leipzig/Germany 2023

Becker, M. **Community Efforts for Research Data Management in Low-Temperature Plasma Physics**. HELPMI Workshop, Berlin/Deutschland 2023

Borghesi, S. M.; Brüser, V.; Kolb, J. F.: **Influence of liquid water and hydrogen on CO₂ conversion for a nanosecond pulsed DBD** 25th Int. Symp. on Plasma Chemistry (ISPC), Kyoto/Japan 2023

Brust, H.: **Effects of Plasma Treated Water on Narrow-leaved Lupin (*Lupinus angustifolius* L.) under Abiotic Stress** 4th Intern. Workshop on Plasma Agriculture (IWOPA), Seoul/South Korea 2023

Chaerony Siffa, I.; Becker, M. M.; Trieschmann, J.: **Towards machine-learned surrogate Poisson solvers for plasma simulations in complex geometries** 4th Int. Conf. on Data Driven Plasma Sciences, Okinawa/Japan 2023

Chaerony Siffa, I.; Becker, M. M.; Trieschmann, J.: **Towards Machine-Learned Poisson Solvers for Low-Temperature Plasma Simulations** DPG-Frühjahrstagung SMuK, Dresden/Deutschland 2023

Chaerony Siffa, I.; Stankov, M.; Becker, M. M.: **Adamant: A JSON-Based Metadata Editor for Researchers** DPG-Frühjahrstagung SMuK, Dresden/Deutschland 2023

Clemen, R.; Bekeschus, S.: **Kaltes Plasma von Wundheilung bis Krebs – die Rolle des Immunsystems** 8. Plasmamedizin-Workshop/44. Workshop des AK-ADP, Göttingen/Germany 2023

Clemen, R.; Bekeschus, S.: **Radical Lessons - Inflammatory Consequences of Medical Gas Plasma Exposure** 1st forum "Our immune system and the rest of the world", Greifswald/Germany 2023

Clemen, R.; Fuentes-Lemus, E.; Bekeschus, S.; Davies, M.J.: **Oxidation of human amylin induces chemical and structural changes and formation of immunogenic products** REDOX BIOLOGY IN TRANSLATION Annual Meeting of the Society for Free Radical Research, Vienna/Austria 2023

do Nascimento, F.; Gerling, T.; Kostov, K. G.: **Influence of the working gas on the temperature of atmospheric pressure plasma jets** XXI B-MRS Meeting 2023, Maceio-Alagoas/Brasil 2023

Dorraki, N.: **Spectroscopic Analysis of pre-strike arc in medium voltage load break switches at different closing speeds. International Conference on Gas Discharges and their Applications** 23rd Int. Conf. on Gas Discharges and their Applications, Greifswald/Germany 2023

Dorraki, N.: **Spectroscopic Analysis of pre-strike arc in medium voltage load break switches at different closing speeds. International Conference on Gas Discharges and their Applications** 23rd Int. Conf. on Gas Discharges and their Applications, Greifswald/Germany 2023

externe Coautoren **Antibiotic resistances spread through wastewater treatment plants – and can be restrained.** Jahrestagung der Vereinigung für Allgemeine und Angewandte Mikrobiologie (VAAM), Göttingen/Germany 2023

Fuentes-Lemus, E.; Clemen, R.; Bekeschus, S.; Davies, M.J.: **Effect of oxidation, chlorination and nitration on the morphology and immunogenicity of the fibril-forming protein amylin** FEBS Advanced Courses, Spesis/Greece 2023

Gonzalez, D.: **Complementary experimental and simulation-based characterization of transient arcs** 24th Symp. on Physics of Switching Arc, Nove Mesto na Morave/Czech Republic 2023

Gonzalez, D.: **Characterization of arc plasma during hybrid-switching using a DC model switch** 68th IEEE Holm Conf. on Electrical Contacts, Seattle/USA 2023

Gortschakow, S.: **Switching behavior of g3 based mixtures** 23rd Int. Conf. on Gas Discharges and their Applications, Greifswald/Germany 2023

Gortschakow, S.: **Modelling of switching arcs at short electrode distances** 23rd Int. Conf. on Gas Discharges and their Applications, Greifswald/Germany 2023

Gortschakow, S.: **DIAGNOSTICS OF PARTIAL DISCHARGES BY COMBINED ELECTRICAL AND OPTICAL MEASUREMENTS** 23rd Int. Conf. on Gas Discharges and their Applications, Greifswald/Germany 2023

Hahn, V.; Schmidt, M.; Weltmann, K.-D.; von Woedtke, T.; Kolb, J.: **Environmentally friendly hydroxylation and dimerization reactions mediated by cold atmospheric-pressure plasma** 14th European Congress of Chemical Engineering and 7th European Congress of Applied Biotechnology (ECCE/ECAB), Berlin/Germany 2023

Hasse, S.; Kantz, L.; Masur, K.; Schmidt, J.; von Woedtke, T.: **Mikrobiologische Analysen und Heilungserfolg nach kINPen MED Einsatz im Rahmen der Plasma-Therapie chronischer Wunden bei Patienten mit Diabetes** 8. Plasmamedizin-Workshop/44. Workshop des AK-ADP, Göttingen/Germany 2023

Hink, R.: **Erste Ergebnisse aus dem biogeniV Basiskonzept Bioraffinerie** 30. REGWA Symposium, Stralsund/Deutschland 2023

Höft, H.; Becker, M.M.; Huiskamp: **Breakdown and development of sub-ns pulsed sparks in short gaps** 23rd Int. Conf. on Gas Discharges and their Applications, Greifswald/Germany 2023

Höft, H.; Becker, M.M.; Kettlitz, M.; Dap, S.; Loffhagen, D.; Weltmann, K.-D.; Naudé, N.; Brandenburg, R.: **Miniaturised Atmospheric Pressure Townsend Discharges in Nitrogen/Nitrous Oxide Gas Mixtures: Role of Associative Ionisation** 23rd Int. Conf. on Gas Discharges and their Applications, Greifswald/Germany 2023

Höft, H.; Ton, C.; Huiskamp, T.; Gerling, T.: **Study on interaction of two single-filament DBDs** DPG-Frühjahrstagung SMuK, Dresden/Deutschland 2023

Jovanovic, A. P.; Höft, H.; Loffhagen, D.; Gerling, T.; Becker, M. M.: **Modelling of self-pulsing discharges at atmospheric pressure** DPG-Frühjahrstagung SMuK, Dresden/Deutschland 2023

Jovanovic, A. P.; Höft, H.; Loffhagen, D.; Becker, M. M.; Gerling, T.: **Study of ion kinetics and ion acoustic wave excitation in self-pulsing discharge in argon at atmospheric pressure** 76th GEC, Ann Arbor/USA 2023

Klose, S.-J.; Bansemer, R.; Brandenburg, R.; van Helden, J.H.: **Impact of feed gas humidity on the discharge dynamics in an Ar-operating atmospheric pressure plasma jet** DPG-Frühjahrstagung SMuK, Dresden/Deutschland 2023

Krös, L.; Harris, B.; Nave, A.; Wagenaars, E.; van Helden, J. H.: **A comparison of the spatial distribution of H₂O₂ in the effluent of the kINPen-Sci and the COST Reference Microplasma Jet** DPG-Frühjahrstagung SMuK, Dresden/Deutschland 2023

Krüger, T.: **Surface and material modification to influence the adhesion of plasma sprayed coatings** 27. Erfahrungsaustausch Oberflächentechnologie, Mühlleithen/Germany 2023

Kruth A. **Green Ammonia for a Carbon-free Energy Economy –Technology Development in CAMPFIRE**. Spring School Hydrogen Technology 2023, Lauenburg/Germany

Kruth A.; Höpfner, D.; Zeretske, M.; Prochnow, S.; Vogler U., Wartmann, J. **CAMPFIRE GreenBalticCruising - Development of a concept for the implementation of new propulsion systems for the use of ammonia as fuel in the Baltic Sea regionn** Ammonia Energy Association Webinar, Virtual Event/Internet 2023

Kruth A.; Wartmann, J.: **CAMPFIRE Partner Alliance: Green Ammonia Technology Development for a Future Hydrogen Economy** North Sea Power House Event, Stuttgart/Germany 2023

Mahdikia, M.; Brüser, V.; Brandenburg, R.: **Operating Barrier Corona Discharges in Argon and CO₂ Gas Mixtures at Elevated Pressure** 23rd Int. Conf. on Gas Discharges and their Applications, Greifswald/Germany 2023

Mahdikia, M.; Brüser, V.; Schiörlin, M.; Brandenburg, R.: **CO₂ Splitting by Barrier Corona Discharge at Elevated Pressure to Optimize the Energy Efficiency and Production Rate of CO** 25th Int. Symp. on Plasma Chemistry (ISPC), Kyoto/Japan 2023

Masur, K.: **Plasma modulation of human progenitor cells isolated from fatty tissue** 2nd Annual meeting of COST Action PlasTHER, Bologna/Italy 2023

Mattern, P.: **Open Laboratory Environment (OLE) Sensor-Net** 2nd Workshop on FAIR Data in Plasma Science, Bochum/Germany 2023

Matthes, R.; Jablonowski, L.; Pitchika, V.; Holtfreter, B.; Eberhard, C.; Seifer, L.; Gerling, T.; Schlüter, R.; Kocher, T.: **Plasmaquellen und -konzepte in der Medizin** 2023 IADR/LAR General Session & Exhibition with WCPD, Bogota/Colombia 2023

Matthes, R.; Jablonowski, L.; Pitchika, V.; Holtfreter, B.; Eberhard, C.; Seifer, L.; Gerling, T.; Schlüter, R.; Kocher, T.: **Decontamination of biofilm covered dental titanium implants by combined treatment with Dental water jet and cold plasma - an in vitro study** 2023 IADR/LAR General Session & Exhibition with WCPD, Bogota/Colombia 2023

Meinke, M.; Hasse, S.; Böckmann, L.: **Vorklinische Untersuchungen einer neuartigen Plasmaquellen** 8. Plasmamedizin-Workshop/44. Workshop des AK-ADP, Göttingen/Germany 2023

Methling, R.: **Investigation of a cadmium discharge utilized in explosion protection by means of optical emission spectroscopy** 24th Symp. on Physics of Switching Arc, Nove Mesto na Morave/Czech Republic 2023

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Guerrero Sanchez: **Effect of pressure on magnetic cores in pressure tolerant electrical systems for subsea applications** (Uni HRO, Elektrische Energietechnik , 11.05.2023)

Hoff, Johannes: **Prätherapeutische Kameradiagnostik in der Plasmabehandlung vom diabetischen Fußulkus - Biostatistische Aspekte einer randomisiertenkontrollierten Studie** (Hochschule Stralsund, März bis Oktober 2022)

Jakub Vokurka: **Simulation and optimisation of a PWM controlled power supply for low current DC multi-arc loads** (Uni HRO, Elektrische Energietechnik , 27.09.2023)

Julia Edelmann: **Kombination von Cisplatin und Plasma beim Harnblasenkrebs** (Universität Greifswald, 29.10.2023)

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Robert Bocek: **Optimization and characterization of a low current high-pressure tungsten arc geometry in nitrogen and methane gas mixtures** (Uni HRO, Elektrische Energietechnik , 27.09..2023)

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Brüggemeier, Nora: **Untersuchung Plasma-induzierter Effekte anhand von 3-dimensionalen Organoid-Zellkulturen (Spheroide)** (Universitätsmedizin Greifswald, 13.01.2023)

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