NEWSLETTER

EDITION 18 — 12/2024

Transient Atmospheric Plasmas
from plasmas to liquids to solids

SFB 1316

CRC ASSISTANCE

Content

Farewell Verena Banach & Welcome Yasmin Breilmann

It is with a mix of gratitude and sadness that we announce Verena Banach's departure from her role as the assistant of CRC 1316 after nearly four years of enthusiastic work. Verena managed all aspects related to the Collaborative Research Center with exceptional diligence. She was responsible for finances as well as the organization of events, ensuring everything ran smoothly. Verena's commitment to the well-being of her colleagues was particularly noteworthy. She always had a listening ear and was there to support her team in any way possible. Her kindness and dedication have left a lasting impact on everyone she worked with.

Although Verena is moving on to a new role on the RUB campus, we are hopeful that her new responsibilities will still bring her into contact with CRC 1316 from time to time. We would like to extend our heartfelt thanks to Verena for all her hard work and wish her all the best in her future endeavors.

We are pleased to announce that Yasmin Breilmann has taken over the role of assistant for CRC 1316 as of November. Yasmin is now the primary contact for all matters related to the Collaborative Research Center and can be reached at the familiar email address sfb1316@rub.de.

We wish Yasmin much success in her new role and look forward to the positive contributions she will undoubtedly bring to our team.

EP2 members & former members

2024 RUB student prize goes to a student of CRC 1316

Huge congrats to Robin Labenski for winning the student prize for his master thesis at the Ruhr University! His master thesis “Laser induced influence of charges in a dielectric barrier discharge under atmospheric pressure” discusses the improvement of plasma catalysts using a metal grid array with cavities of diameters between 50 and 200 µm. Using an Nd:YAG laser, the surface charges of the reactor could be manipulated to investigate the behaviour of the discharge.

Fun fact: Project A6, where this thesis was set, seems to be very successful in winning this prize. 2021 David Steuer won it for his master thesis and in 2023 Henrik van Impel won the prize with his bachelor thesis.

Martha Finke, public relations

Tim Dirks wins Uwe Kappel doctoral prize

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Congratulations to Tim Dirks, who has been awarded the Uwe Kappel doctoral prize. His PhD thesis entitled “Plasma-driven biocatalysis and the investigation of plasma-protein interactions“, addresses three challenges in plasma-driven biocatalysis: the inactivation of enzymes by reactive plasma species, the limited production rate of H_2O_2, and the limited availability of suitable biocatalysts. His outstanding work on a successful strategy to protect enzymes by immobilising and binding them to beads has significantly increased the efficiency of plasma-driven biocatalysis.

The Uwe Kappel doctoral prize was awarded for the first time in November 2024. The prize was established by the Faculty of Biology and Biotechnology in cooperation with the Society of Friends of the Ruhr University to support young researchers and to honour their outstanding achievements during their doctoral studies.

For more information on Tim Dirks‘ research and the progress of project B8, see page 12.

Ida Hülsbusch, public relations

Impact of the surface on $He(2^3S_1)$ and $He_2(a^3\Sigma_u^+)$ metastables densities in atmospheric pressure RF plasma

Siqi Yu, Laura Chauvet, Achim von Keudell

Atmospheric pressure plasmas have drawn growing attention in recent years because of their broad applications in different fields. Non-thermal plasma (NTP) can be used in material processing, medical treatment, material deposition and synthesis, and gas conversion.

In this study, a radio-frequency (RF) helium discharge is used to generate a homogeneous discharge. The helium metastable species act as an energy pool and exhibit a high chance of colliding with other particles due to their long lifetime, and play a crucial role during the discharges. Broadband absorption spectroscopy is used to measure the density of atomic $He(2^3S_1)$ and molecular $He_2(a^3\Sigma_u^+)$ metastables. Different surfaces are used to discuss the influence of materials on helium metastable reaction dynamics.

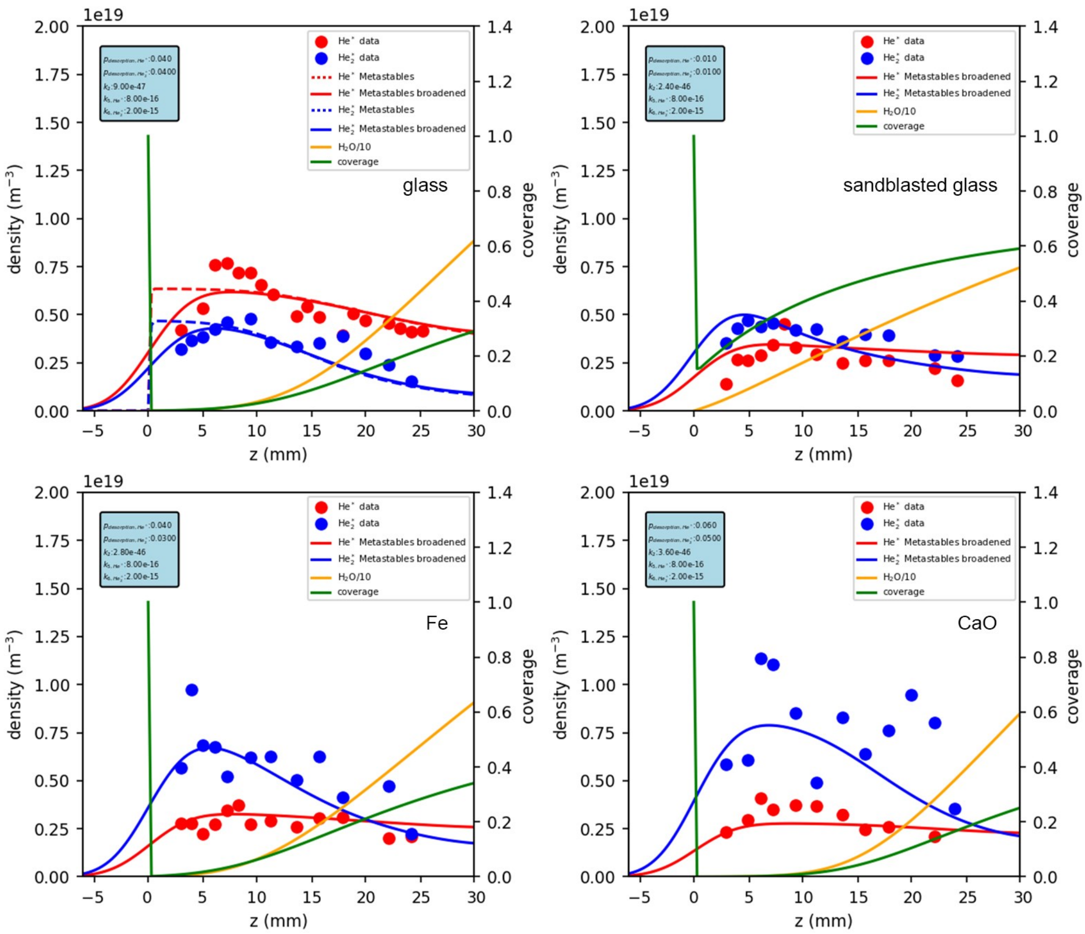


Figure 1: The experimental (points) and simulation (solid lines) results of the He* (red) and He_2* (blue line) for different surface materials

Figure 1 shows the spatial distribution of metastable species along a plasma channel. An 1D chemical kinetics model describes the two trends in the space-dependent variation and fits well with the experimental data. (i) The decrease of metastable density along the plasma channel is assumed to be caused by their interaction with impurities. These impurities, such as water molecules, may accumulate along the plasma channel due to the impact of metastables at the chamber walls, which leads to the desorption of adsorbed water (or other species) into the gas phase. (ii) The metastable densities change with the surfaces. The $He_2(a^3\Sigma_u^+)$ has the highest density in front of a CaO surface. The efficiency for conversion of $He(2^3S_1)$ into $He_2(a^3\Sigma_u^+)$ seems to be higher for low work function materials.

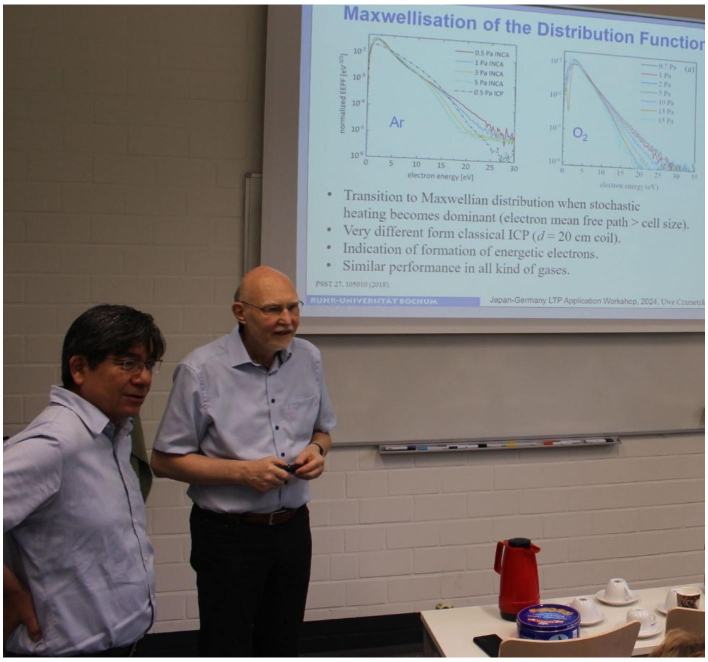
Leslie (Siqi) Yu, project A3

[1] S Yu et al, 2024 *Plasma Sources Sci. Technol. 33 115015*

View paper

Japanese-German workshop on low-temperature plasma applications

A workshop with guests from Japanese universities/research institutions and members of the chair of Experimental Physics V was held on 25th and 26th of July. Initiated by Prof. Aramaki from Nihon University in Chiba, the workshop brought together long time colleagues who stayed as collaborators at EP V during the last 20 years. All of them conduct research in the field of low temperature plasmas. This covers a broad range, from the applications for agriculture or semiconductor fabrication to developing new kinds of diagnostics like vortex laser spectroscopy. With these topics, a perfect overlap with the research of the CRC is given so that the workshop consists not only of one day of presentations but also one day of laboratory visits allowing for the guests to get an overview of the current local plasma research.



Dirk Luggenhölscher, project A2

SFB summer meeting

From June 19 to 21, 2023, the CRC 1316 Summer Meeting has been held in Hamminkeln-Dingden. The meeting was a great success and was accompanied by a lively participation of all stakeholders. The event provided an excellent opportunity for scientists to present and discuss their research results. In addition to the lectures, there were also many opportunities for informal talks and discussions. These discussions led to an intensification of collaboration and offered participants the opportunity to establish new contacts and deepen existing relationships.

Ida Hülsbusch, public relations

The role of flow field dynamics in enhancing volatile organic compound conversion in a surface dielectric barrier discharge system

Alexander Böddecker, Maximilian Passmann, Angie Natalia Torres Segura, Arisa Bodnar, Felix Awakowicz, Timothy Oppotsch, Martin Muhler, Peter Awakowicz, Andrew R Gibson, Ihor Korolov

Non-thermal atmospheric pressure discharges are increasingly being utilized in industrial applications. Dielectric barrier discharges (DBDs) are particularly useful in tasks such as ozone generation, UV and VUV radiation generation, and pollution control or surface treatment. For high-flow gas treatment, Surface-DBDs (SDBDs) offer a key advantage: they are not limited by the small gas gaps between electrodes, making them ideal for scalable systems with low flow resistance.

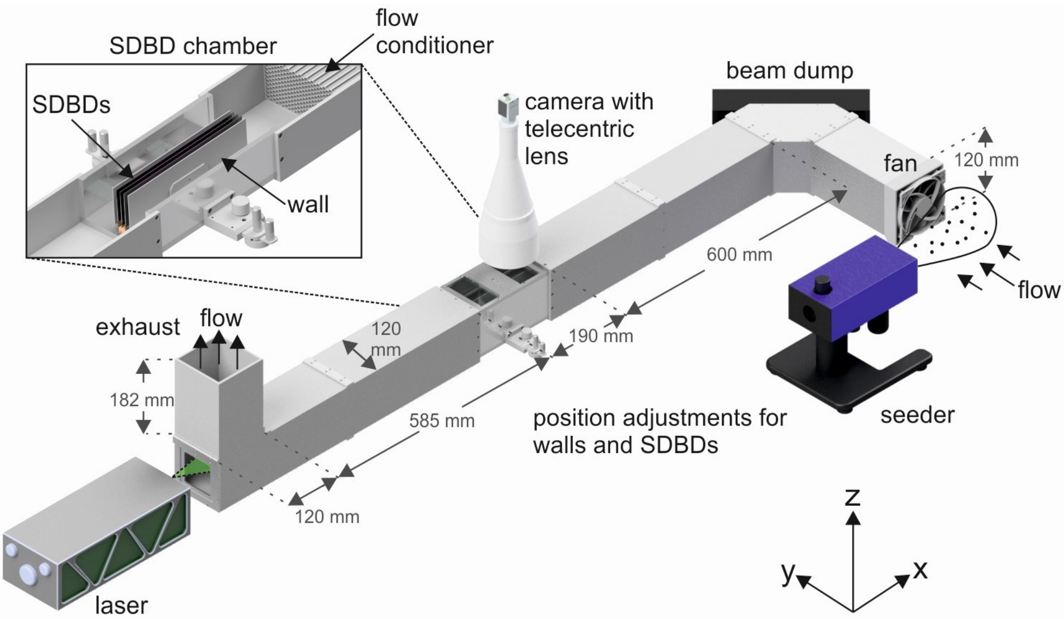


Figure 1: Setup of the VOC conversion plasma.

In SDBDs, reactive species can easily interact with larger gas volumes, providing a more application-oriented approach for gas treatment. Our SDBD source from the “Chair of Applied Electrodynamics and Plasma Technology” has already shown substantial potential for the abatement of volatile organic compounds (VOCs). In a recent publication, we explored its capability to induce complex flow patterns above the electrodes via electrohydrodynamic forces, hypothesizing that these induced flows play a critical role in the VOC conversion process. This phenomenon has been studied for decades in plasma actuators, primarily to improve fluid dynamics in machinery and aeronautics.

Our novel study explores the enhancement of VOC conversion efficiency through the manipulation of flow field dynamics in this SDBD system. Focusing on *n*-butane as our benchmark VOC, we analyzed the interplay between plasma-induced flow fields and chemical conversion processes using advanced particle image velocimetry (PIV) setup, which is shown in figure 1. The results reveal that specific vortex structures (visible in figure 2), induced by the discharges, create enhanced mixing conditions for VOC molecules, leading to an increase in conversion efficiency. Notably, the highest conversion was achieved at a gap distance of 16-22 mm between two parallel operated SDBD electrodes, where the vortices enable an improvement in gas mixing, thus amplifying the chemical reactivity of the total system.

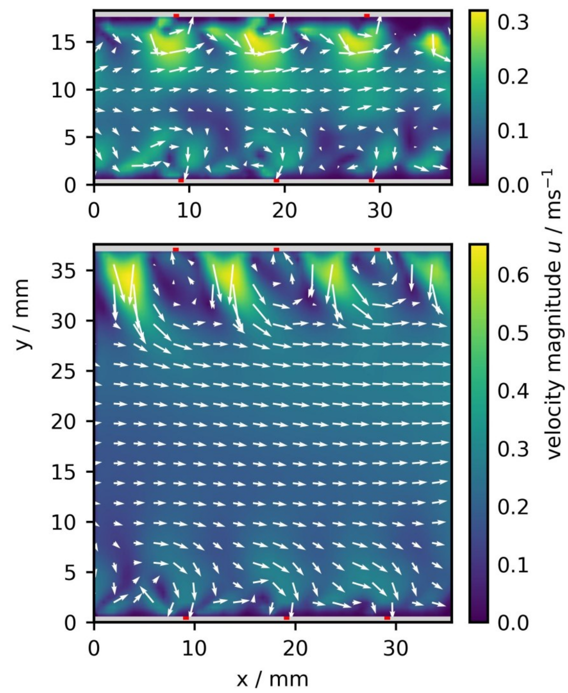


Figure 2: The flow of the gas reveals specific vortex structures, which enhance the mixing of VOCs. The upper figure shows a gap of 16 mm whereas the lower image shows a 36 mm gap.

The measurements suggest significant potential for optimizing gas treatment processes which are important for the upscaling of the system. In our future investigations, we will focus on tailored fluid flows and proceed with our simulations to calculate optimized grid geometry, as well as three-dimensional fluid flows.

Alexander Böddecker, project A7

[1] Alexander Böddecker et al, 2025 J. Phys. D: Appl. Phys. **58** 025208

View paper

Annual CRC fall meeting

This year's fall meeting, which took place from 12th until 14th November, was held at the Ruhr University Bochum.

Scientists held talks about the progress within their projects, networked to identify common challenges and attended a workshop on working with commercial plasma simulation tools.

All in all, it was an enriching event and we are looking forward to meet again in spring.

Martha Finke, public relations

Two PhD students at Hakone conference

At the 18th Hakone in Padua (Italy) (01.09-06.09), Soad Mohsenimehr and Henrik van Impel (A6) each gave an oral presentation on recent results from their research projects. The conference was filled with many interesting presentations on low temperature plasmas at atmospheric pressure and their potential in plasma chemical processes. In particular, dielectric barrier discharges were discussed during the conference in terms of efficiency in connection with catalysts and fundamental physical discharge dynamics. In addition to the many profitable insights into many different research projects, the conference provided an excellent framework for the PhD students to make international connections with other participants from a total of 24 countries.

Henrik van Impel, project A6, Soad Mohsenimehr

50th EPS conference in Palacio

Jun.-Prof. Judith Golda participated in the 50th EPS Conference on Plasma Physics, which took place at Palacio de Congresos Salamanca, Spain from 8 -12 July 2024.

She was invited to hold a plenary talk on “Atmospheric pressure plasma: From basic physics to environmental applications”.

With numerous plenary speakers and invited talks by researchers from universities and laboratories all around the world, this annual conference covers the wide field of plasma physics including magnetic confinement fusion, beam plasma and inertial fusion, low temperature plasmas, and basic, space and astrophysical plasmas.

Ida Hülsbusch, public relations

Five posters at ESCAMPIG

This year's ESCAMPIG conference took place in Brno, Czech Republic. Three members of Experimental Physics II and one member of AEPT from Bochum took part and contributed to the conference with five posters. In addition to the interesting plenary lectures by well-known personalities such as Peter Bruggeman (USA), Luís L. Alves (Portugal), Kinga Kutasi (Hungary) and Holger Kersten (Germany), there was a variety of around 160 other posters on both modelling and experimental topics. In addition to the professional exchange, the conference offered excellent evening events, such as the welcome party with a dance class and Czech specialities or the conference dinner with live music and a cosy atmosphere. We had many interesting discussions at the conference and met new and old acquaintances, which is why we came back from the conference with very positive experiences overall.

Jonas Thiel

ISPCEM success: prize awarded to Steijn Vervloedt

Gabriel Boitel-Aullen (B13) and Steijn Vervloedt (A3) took part in the 6th International Symposium on Plasmas for Catalysis and Energy Materials (ISPCEM) in Eindhoven, from 10th to 12th of July.

During the two and a half day event, presentations were given on the latest advances in plasma catalysis, ranging from nitrogen fixation to the dissociation of CO_2 and the formation of hydrocarbons. This highlights the easiness of installing and operating such discharges. Also, a few presentations on the plasma assisted synthesis of catalysts were given, which is the topic of project B13.

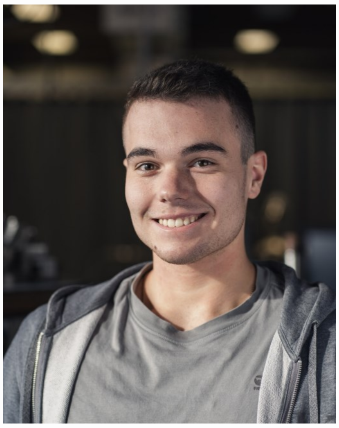
Our researches were allowed to orally present the recent developments of their projects, where Steijn got awarded with the best oral presentation.

Steijn Vervloedt, project A3

NEW FACES IN THE CRC & SCHOOL

Anna Karolyna Gomes, originally from Rio de Janeiro, Brazil, holds a Bachelor’s degree in Chemistry and Physics from the Federal University of Rio de Janeiro. Her academic background provided a solid foundation in Density Functional Theory and other electronic structure methods, developed through both her undergraduate and master’s research.

Since 2024, she has been a PhD student at Ruhr University Bochum, working on project B14 of the CRC 1316. Her research aims to gain atomistic insight into the behavior of solvated electrons under plasma-like conditions, with a particular focus on investigating the influence of electric fields and solid interfaces. The solvated electron plays a key role in many different reactions, and understanding its behavior can lead to a variety of applications in fields such as plasma chemistry, electrochemistry, and CO_2 conversion.



Daniel Henze studied physics with a special emphasis on plasma physics at the Ruhr-University Bochum. During his bachelor thesis, he took part in the PROCOPE project, whose objective was the investigation of production pathways and the role of carbon monoxide in the plasma treatment of biological material. As a contribution to the project, the topic of his thesis was the measurement of CO densities in a coplanar RF-plasma jet using mass spectrometry.

Continuing his study of plasma physics, his master thesis dealt with the diagnostic challenges encountered when conducting mass spectrometry of ions from a kHz dielectric-barrier-discharge plasma jet, with special emphasis on temporally and energetically resolved measurements.

In February 2024, he will start as a PhD student in the A3 project in the CRC 1316.

The objective of this project is the investigation of the plasma chemistry in plasma catalytic processes based on chemical looping. His research will focus specifically on the use of atmospheric pressure plasma jets in plasma catalysis.

Alexander Schicke successfully completed his Master's degree in physics at the Ruhr University Bochum this year. During his studies, he worked intensively with TDLAS (Tunable Diode Laser Absorption Spectroscopy) to determine the densities of metastable helium and argon atoms. The aim of his research was to find out how these atoms behave when the mixing ratio of helium and argon in the COST jet plasma is changed in order to investigate the effects on the dissociation of CO_2. As part of his PhD position in project B2 of the CRC 1316, he will focus on research into new catalysts for the electrochemical reduction of CO_2. His aim is to improve the efficiency and sustainability of these processes by developing and optimising nanostructured materials. He will use state-of-the-art analytical methods and experimental techniques to better understand the underlying mechanisms and develop innovative solutions.

Plasma School and Master Class in Bad Honnef

From 5th to 10th October 2024 the plasma school in Bad Honnef, took place.

Amy Cheng attended as a PhD Student and learned a lot about plasma diagnostics, plasma modelling and microplasma sources.

Directly after the school, the master class on plasmas, liquids and nanomaterials began. It was a weekend packed with networking, learning about plasma produced nanoparticles and sputtering onto liquids. All in all, it was a great opportunity to learn more about plasma physics.

Martha Finke, public relations

ICPM10 and Summer School on Plasma Medicine

The 10th International Conference of Plasma Medicine and the 9th International Workshop on Plasma for Cancer Treatment took place in Portorose, Slovenia, from September 8th to 13th. The conference provided an excellent platform for knowledge exchange in the multidisciplinary field of plasma biomedicine. Sabrina Klopsch represented the research group in project B11 of the CRC 1316 and gave a talk titled “Expanding plasma-driven biocatalysis using unspecific peroxygenase from Collariella virescens and a capillary plasma jet”.

In conjunction to the ICPM 10, the summer school on plasma medicine was held.
Prof. Dr. Julia Bandow from the Department of Applied Microbiology at the Ruhr University Bochum joined the summer school as a teacher. She held a lecture on “Plasmas in pharmaceutical applications, biochemistry and biomolecular engineering”.

Ida Hülsbusch, public realtions

Advancements in plasma-driven biocatalysis: Protecting enzymes from plasma-mediated inactivation

Tim Dirks, Marco Krewing, Katharina Vogel, Abdulkadir Yayci, Sabrina Klopsch, Wuyuan Zhang, Frank Hollmann, Julia E. Bandow

Within project B8 of the CRC 1316, we are working on the optimization of plasma-driven biocatalysis, which utilizes *in situ* H_2O_2 production by plasmas tailored to drive H_2O_2-dependent enzymes while preventing their inactivation due to excess H_2O_2. One of the key challenges we face is the interaction between plasma-generated species and enzymes, which can result in the inactivation of the enzymes. This currently undermines the efficiency of plasma-driven biocatalysis.

Understanding the impact of plasma species on protein stability

Through our studies we have developed a deeper understanding of how plasma-generated species interact with proteins, potentially leading to significant structural and functional changes. Plasma treatments generate a complex mixture of reactive oxygen and nitrogen species (RONS). These highly reactive species pose a threat to protein stability, as they can lead to oxidative modifications that disrupt protein structure and function. In our research with the protein Hsp33, we specifically focused on identifying which plasma-generated reactive species are capable of activating or modifying the protein. We found that certain reactive oxygen species, such as superoxide, singlet oxygen, and atomic oxygen, are key players in the activation of Hsp33 *in vitro*. These species effectively interact with the protein, triggering a conformational change of the protein. On the other hand, we found no evidence of activation by ozone, peroxynitrite, or hydroxyl radicals. These findings suggest that the balance of plasma species and their interaction with proteins is crucial for plasma-driven biocatalysis. Understanding which species are especially detrimental helps us to better tailor plasma conditions for enzyme survival to minimize the risk of harmful oxidative damage.

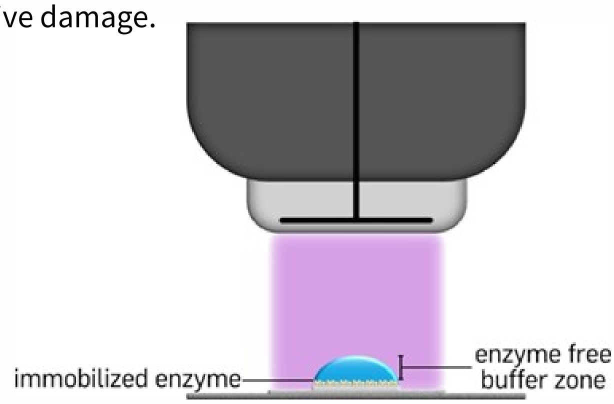


Figure 1: Schematic overview on treatment of immobilized enzymes with the Cinogy DBD plasma source and the creation of an enzyme-free buffer zone.
Taken from Dirks et al. J R Soc Interface.

Immobilization as a solution to protect enzymes

To address the challenge of plasma-induced enzyme degradation, we turned to enzyme immobilization as a potential strategy for protection. Immobilizing enzymes onto solid supports has long been a recognized method for improving enzyme stability, and we aimed to investigate its efficacy in the context of plasma exposure. We discovered that immobilization significantly enhances the stability of enzymes when exposed to plasma treatments. Immobilization was initially believed to protect enzymes from plasma-mediated inactivation by creating a buffer zone between the enzymes and the plasma-exposed liquid surface (Figure 1). This aqueous layer allows short-living, highly reactive plasma species - considered most harmful to proteins - to recombine before reaching the immobilized enzymes. However, since different carriers offer varying levels of protection, other factors

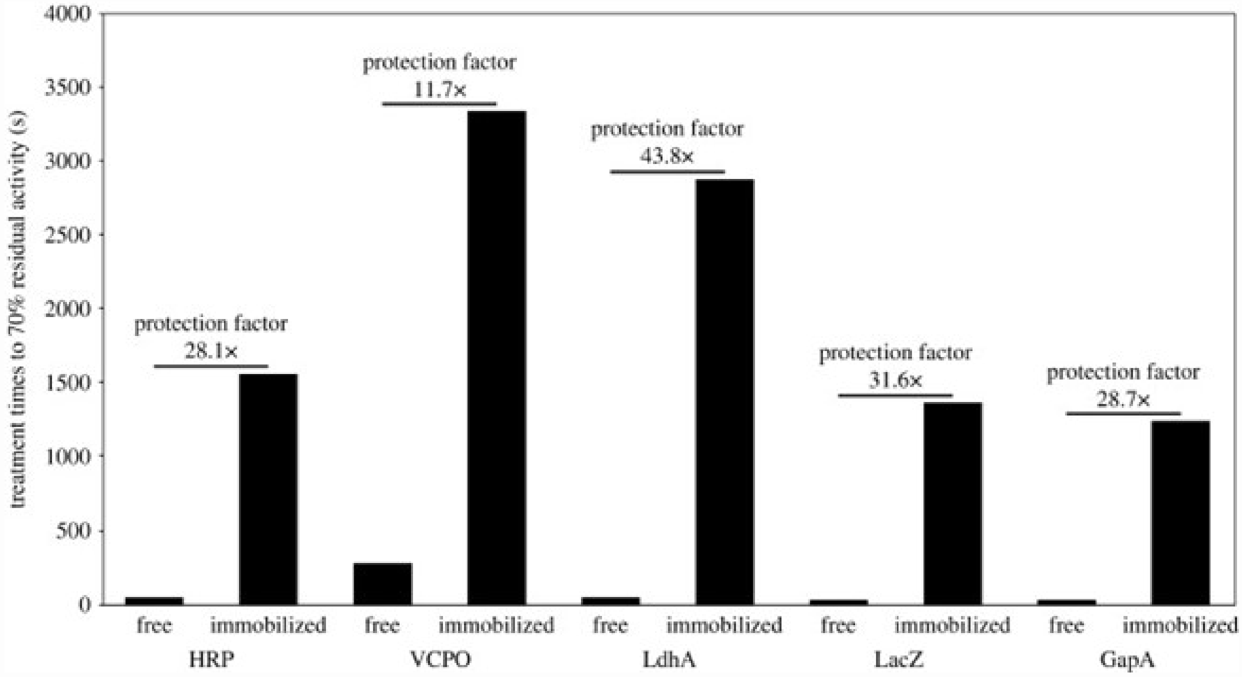


Figure 2: Treatment times at which residual enzyme activity of free and immobilized investigated proteins (HRP, VCPO, LdhA, LacZ and GapA) reached 70%. HRP, VCPO, and LacZ were immobilized on epoxy-butyl-functionalized resin, LdhA and GapA on amino-functionalized resin following manufacturers' instructions. Taken from Dirks et al. J R Soc Interface.

seem to be involved. The carrier material might act as a scavenger, using free functional groups to interact with plasma-derived species, preventing them from reaching the enzymes. We found that covalent immobilization techniques offered the most effective protection. This was especially true for hydrophobic supports, where we saw up to 44 times longer enzyme activity compared to free enzymes under plasma exposure (Figure 2). These hydrophobic surfaces likely repelled plasma-generated species, preventing them from interacting with the enzyme itself. Additionally, we also noted that immobilization could reduce the degradation of enzymes.

Implications for plasma-driven biocatalysis

Our findings highlight the importance of enzyme protection in the context of plasma-driven biocatalysis. We found that plasma-induced inactivation of enzymes is a significant challenge, primarily driven by enzyme modifications due to long-living reactive species and enzyme degradation due to short-living species. However, we also found that enzyme immobilization provides a practical and highly effective solution to this challenge. By using immobilized enzymes, particularly those bound to hydrophobic supports via covalent interactions, we were able to extend enzyme lifetimes and enhance their stability in plasma environments.

Tim Dirks, project B8

[1] Dirks T, Krewing M, Vogel K, Bandow JE. The cold atmospheric pressure plasma-generated species superoxide, singlet oxygen and atomic oxygen activate the molecular chaperone Hsp33. J R Soc Interface. 2023 Oct;20(207):20230300. doi: 10.1098/rsif.2023.0300.

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[2] Dirks T, Yayci A, Klopsch S, Krewing M, Zhang W, Hollmann F, Bandow JE. Immobilization protects enzymes from plasma-mediated inactivation. J R Soc Interface. 2023 Oct;20(207):20230299. doi: 10.1098/rsif.2023.0299.

View paper

One topic, two master thesis‘, two papers

Henrik van Impel & Robin Labenski, David Steuer, Volker Schulz-von der Gathen, Marc Böke and Judith Golda

Last year, Henrik van Impel and Robin Labenski completed their synergistic master's theses as part of project A6, investigating the micro-cavity plasma array (MCPA), a form of dielectric barrier discharge. The results of their research were recently published in two separate papers. Henrik focused on characterizing the strength of the electric field components within the MCPA, while Robin examined the deposition of surface charges on its dielectric barrier. Both, electric fields and surface charges are known to influence catalytic activity, but their effects in plasma catalysis remain unknown. Their work represents a step forward, enabling the first experimental investigation into these interactions and their impact on catalysis.

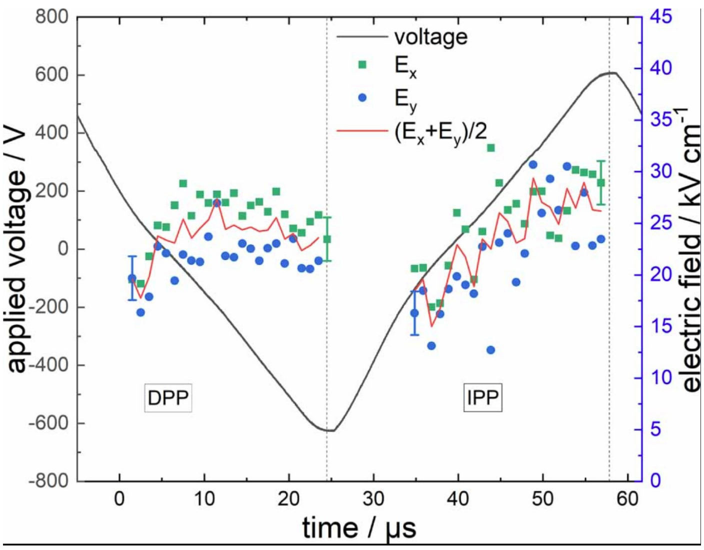


Figure 1: Temporal evolution of the field components in the decreasing and increasing potential phase (DPP/IPP) with a 1 µs time resolution at 600 V applied voltage amplitude .

The first thesis by Henrik focuses on the electric field components in the MCPA. The diagnostic approach is based on the Stark effect and its influence on the shifting and splitting of a helium line pair. These changes in the line pair were observed using polarized optical emission spectroscopy. With that technique, Henrik carried out phase-resolved measurements of the electric field components with a time resolution of 1 µs and showed that the field strength perpendicular to the dielectric surface, where a catalyst can be placed, is about 22 kV/cm in one half-phase of the excitation cycle. In comparison, the parallel component is about 5 kV/cm higher. These findings are important for optimizing catalytic efficiency in plasma processes.

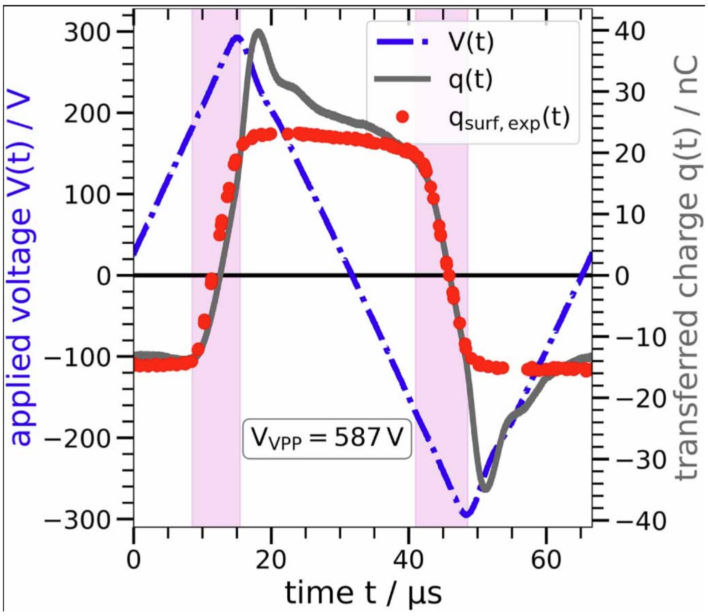


Figure 2: Time-resolved surface charge (red) during the MCPA's cycle. The intervals highlighted in pink denote the discharge phases.

Robin's thesis explored methods for determining and manipulating surface charges. The first approach involves shutting down the reactor at precisely controlled times to quantify surface charges left on the dielectric by the plasma. By adjusting the timing of the shutdown within the plasma cycle, the remaining surface charge can be finely tuned. To further modulate surface charging during plasma operation, he also employed a nanosecond laser to generate free charges at the electrodes. These charges are amplified by the plasma and accelerated towards the dielectric, enabling additional surface charging by up to 15 %. His findings revealed that the plasma responds sensitively to these additional charges, igniting at lower voltages in subsequent cycles as it seeks to compensate for the altered charge distribution. Both techniques offer valuable tools for plasma catalysis, as they allow for the controlled charging of catalytic dielectrics during or after plasma operation.

Robin Labenski & Henrik van Impel, project A6

[1] Robin Labenski *et al* 2024 *Plasma Sources Sci. Technol.* **33** 105022

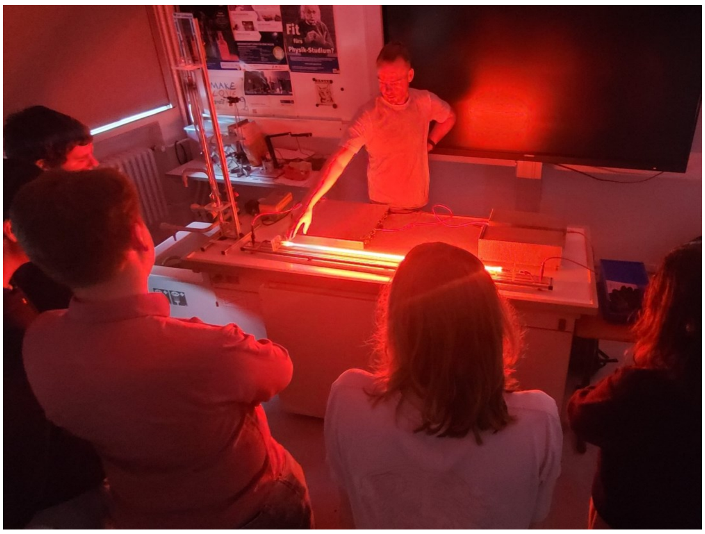
[2] Henrik van Impel *et al* 2024 *Plasma Sources Sci. Technol.* **33** 105008

View Robins paper

View Henriks paper

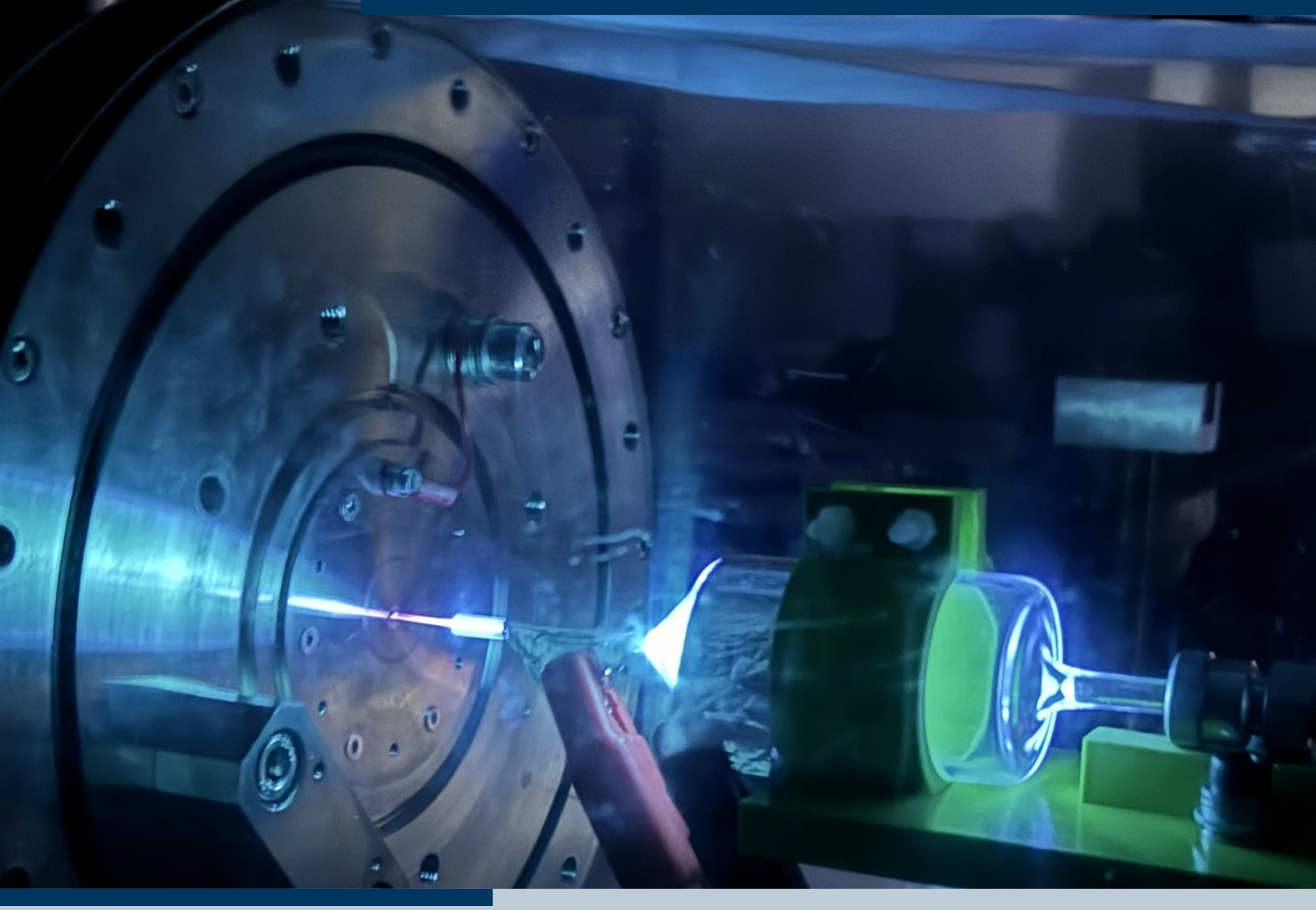
Workshop for school students

The plasma truck is on the road again! On 20th June, physics students and PhD students in physics and electrical engineering from Ruhr-University Bochum visited the Burggymnasium Essen. The high school students from grades 11 and 12 participate in the mobile workshop. They conducted exciting plasma experiments, used a spectrometer to analyse the light emission and observed how plasmas can be influenced by electrical and magnetic fields. The workshop was a success and the students showed great interest.



Although plasma physics is not part of the curriculum, some experiments in school lessons involve plasmas. The mobile workshop was developed to familiarise high school students with the concept of plasma. Experiments were designed that can be transported to school in a minibus. During the 90-minute workshop, the students experiment in small groups and learn about plasmas and their various applications.

Ida Hülsbusch, public relations



IMPRESSUM

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