NEWSLETTER

EDITION 16 — 12/2023

SFB 1316 Transient Atmospheric Plasmas
from plasmas to liquids to solids

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Foreword

Dear readers,

As this issue begins, I am delighted to introduce you to a number of new faces who have become an integral part of our vibrant community. This issue is full of exciting developments, from insightful conferences to dynamic outreach initiatives. One particularly notable addition to our portfolio is the introduction of Project B14, a project that promises a more thorough understanding of the interface between plasma, liquid and solid.

In the spirit of progress, I must also share the bittersweet news of bidding farewell to a valued member of our team. After contributing her expertise since 2020, we extend our heartfelt thanks to Maike Kai for her unwavering dedication. Maike played a pivotal role in the Public Relations team, leaving an indelible mark with her creative ideas and commitment to keeping everything running smoothly. Her invaluable contributions were not limited to the office, as she played a crucial role in organizing the school students project week. We wish Maike the very best in her future endeavors.

Amidst this change, we are delighted to welcome Lara Boeddinghaus and Sebastian Belzer to our team. Lara brings her unique perspective, while Sebastian, hailing from the field of Electrical Engineering, promises fresh insights and expertise. Their presence undoubtedly enhances the diverse skill set within our team, and we look forward to the collaborative endeavors that lie ahead.

Marina Prenzel, public relations

Prof. Dr. Julia Bandow in DFG Review Board and Prof. Dr. Beatriz Roldán Cuenya honored with Manchot Research Professorship

Prof. Dr. **JULIA BANDOW** from the Department of Biology and Biotechnology has been elected to the review board of the German Research Foundation (DFG) and is assigned to the review board 2.21: Microbiology, Virology and Immunology, subject: 2.02 Microbial Ecology and Applied Microbiology for the term of office from 2024 to 2028.


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Approximately 150,000 researchers are eligible to vote in the review board election, which is held every four years. The review boards are responsible for evaluating proposals submitted to the DFG. To identify the projects most worthy of funding within the given financial framework, the review boards compare and assess all projects according to uniform standards. Moreover, the review boards are also involved in the further development of the funding programs.

Prof. Dr. **BEATRIZ ROLDÁN CUENYA** was awarded the Manchot Research Professorship, becoming the first woman to receive this prestigious honor. The award is presented annually by the Jürgen Manchot Foundation to outstanding scientists.

In addition to recognizing her exceptional scientific contributions, the foundation provides the opportunity for the award winner to teach at the Chemistry Faculty of the Technical University of Munich.

Ida Hülsbusch, public relations &
Dr. Jelena Tomović, FHI Press and Public Relations Officer

Upcoming events

20 Feb.
PI Meeting
Location: RUB

21 Feb.
MGK Colloquium
Location: Heidelberg

13 Mai *(not yet fixed)*
RDM Workshop
Location: Kiel

01 Jul.
General Assembly
Location: Hamminkeln-Dingden

PAPER REPORT

Validation of in situ diagnostics for the detection of OH and H_2O_2 in liquids treated by a humid atmospheric pressure plasma jet

Steffen Schüttler, Ludwig Jolmes, Emanuel Jeß, Kristina Tschulik, Judith Golda

Plasma-treated liquids find their applications in various fields like plasma medicine, bacteria inactivation or plasma-driven biocatalysis. The knowledge of the delivery of reactive species from the plasma to the liquid, their solubility and their distribution in the liquid are of interest for intended application. For example, in the plasma-driven biocatalysis process investigated in projects B8 and B11, H_2O_2 from an atmospheric pressure plasma jet is used in a plasma-treated buffer solution to convert ethylbenzene to R-1-phenylethanol in the presence of AaeUPO (unspecific peroxygenase) [1].

In this work, we investigated different liquid diagnostics for the detection of OH and H_2O_2 in the plasma-treated liquid [2]. The plasma source used was a capillary plasma jet with similar characteristics to the COST reference plasma jet, but extended by a capillary between the two electrodes to prevent the transition to arc mode. The feed gas consisted of helium enriched with water vapor provided by an ice-cooled bubbler system.

H_2O_2 was detected by two diagnostics. First, a spectrophotometric approach was used in which the reagent ammonium metavanadate (NH_4VO_3) reacts with H_2O_2 to form a red-orange peroxovanadium cation solution. The absorbance of this solution at 450 nm can be measured in-situ during plasma treatment. The second method was based on the electrolysis of H_2O_2 with a Prussian blue carbon paste electrode performed ex-situ after plasma treatment. Calibrations were performed for both diagnostics and linear relationships were found for both.

The comparison of the two diagnoses is shown in Figure 1 (a) for two humidity concentrations of the feed gas and different plasma powers. There is excellent agreement between the two diagnostics. At low powers and correspondingly low H_2O_2 concentration, the electrochemical sensor measurement underestimates the H_2O_2 concentration as it is below the detection limit.

In the case of OH, its distribution was visualized by the chemiluminescence (CL) of luminol. Luminol is excited by strongly oxidative species such as OH or the superoxide O_2^-. The deexcitation of excited luminol takes place at a wavelength of 425 nm and is measured with an iCCD camera. In this way, a 2D image of the CL of luminol could be obtained. The terephthalic acid (TA) dosimeter was used to measure the OH concentration in the treated liquid. TA reacts with OH to form 2-hydroxy-terephthalic acid (HTA). HTA can be measured by illuminating it with UV light at 310 nm and measuring its fluorescence at 425 nm using an iCCD camera with a filter in front of the camera. The signal was recorded at a depth of 8 mm in the liquid. Calibration of the system was performed with known HTA solutions.

Figure 1 (b) shows the comparison of the two OH diagnostics. Here, the mean CL signal of luminol was measured at the liquid surface. Again, both diagnostics show excellent agreement with a linear increase of both signals with increasing plasma power. Two conclusions can be drawn from this comparison.

View paper

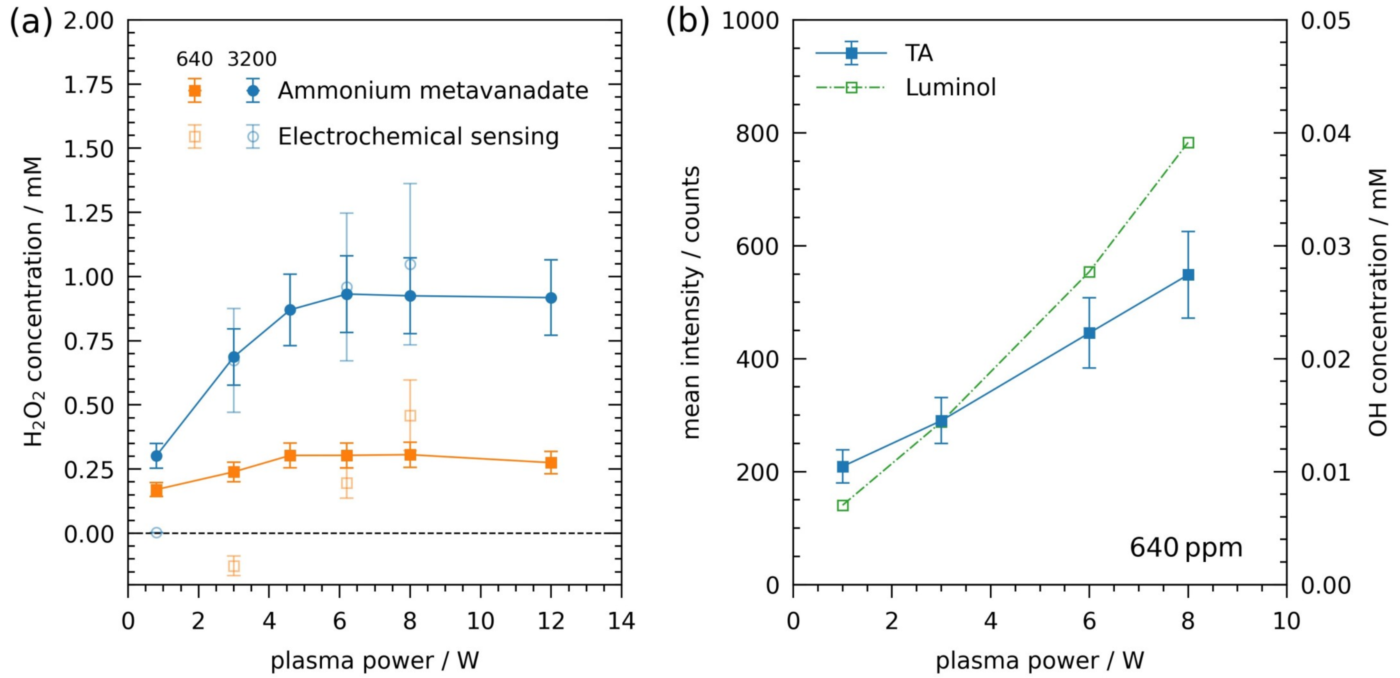


Figure 1: (a) H_2O_2 concentration as a function of plasma power at humidity concentrations of 640 ppm and 3200 ppm, measured with a spectrophotometric approach using ammonium metavanadate and electrochemical sensors. (b) OH distribution measured by chemiluminescence of luminol and OH concentration measured by terephthalic acid (TA) dosimeter as a function of plasma power at a humidity of 640 ppm.

The volume-averaged TA measurement follows the luminol measurements at the liquid surface. It is likely that the reaction between OH and TA takes place at the liquid surface and that the reactant HTA diffuses through the liquid into the measured volume. Thus, it is plausible that the volume-averaged measurement shows the same trends as the surface measurement. Secondly, the CL at the surface of the plasma-treated liquid follows the same trends observed with the OH-sensitive TA dosimeter. It can therefore be assumed that the CL of luminol visualizes the distribution of the OH radical.

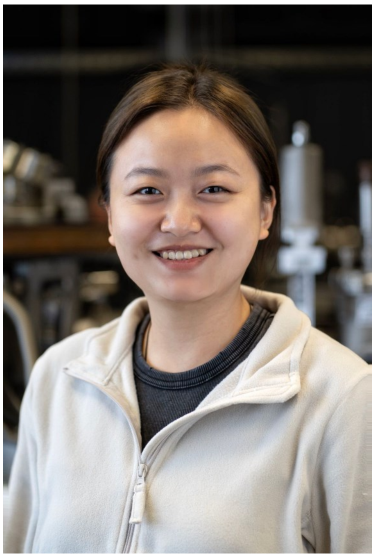
The results of our work show that the detection of H_2O_2 and OH in a plasma-treated liquid can be performed with different diagnostics that validate each other. Each diagnostic has its advantages and disadvantages. The spectrophotometric approach requires the addition of ammonium metavanadate, but can be used in situ. The electrochemical sensor selectively measures H_2O_2, but can only be performed ex-situ in the plasma-liquid configuration used. CL of luminol shows the distribution of OH, but cannot be used to measure absolute concentrations. This can be done with the TA dosimeter. Finally, it must be mentioned that these investigations were performed in a controlled system consisting only of helium and water vapor. The results could be different when working in a more reactive system, which could be the case if nitrogen is also present in the feed gas. This is to be investigated in a follow-up study.

Steffen Schüttler, project B11

[1] A. Yayci, T. Dirks, F. Kogelheide, M. Alcalde, F. Hollmann, P. Awakowicz, J. E. Bandow, ChemCatChem 2020, 12(23), 5893. doi: 10.1002/cctc.202001225

[2] Schüttler, S., Jolmes, L., Jeß, E., Tschulik, K., Golda, J., Plasma. Process Polym. 2023, e2300079. doi: 10.1002/ppap.202300079

NEW SCIENTISTS WITHIN THE CRC 1316



Amy cheng studied plasma physics in Dalian Maritime University in China.
She joined our group as PhD student in September 2023 and will work with Henrik van Impel in project A6. Project A6 aims at a fundamental understanding of the interaction between the plasma and the catalytic surface. Her research will focus on temperature control of the catalytic surface to optimize reactivity and ultimately conversion rates achieved with DBD. The optimization will be investigated by measuring the atomic oxygen production using TALIF and SEA.

Inna Orel joined the CRC 1316 in November 2023 and works as a postdoc in project A1. Originally she is from Kyiv and started her academic career in 2015 with her Bachelor's degree in physics at Taras Shevchenko Kyiv National University. Afterwards, she moved to France, where she undertook a comprehensive Master's course in plasma physics at the University of Pierre and Marie Curie, Paris. During her second year of Master's studies, Inna crossed paths with Svetlana Starikovskaia, who soon became her Ph.D. supervisor. Under Starikovskaia's guidance, Inna completed her Ph.D. thesis entitled "Measurements of electric field and dissociated species in nanosecond discharges for kinetic and biological applications." This extensive research, conducted over three years at LPP, Palaiseau, France, culminated in the successful defense of her thesis in 2020.

Throughout her doctoral research, Inna primarily focused on optical methods for measuring electric fields (E-FISH) and atomic species number density (optical actinometry, TALIF). She explored the interaction between cold plasma and biological targets, specifically mesenchymal stem cells.
Following the completion of her Ph.D., Inna continued her scientific work with two post-doctoral positions at GREMI, France. Under the mentorship of Eric Robert and later Claire Douat, she studied disinfecting and immuno-stimulating possibilities associated with cold plasma treatment containing O, N, and CO for bacteria and hemoglobin.
Currently, Inna has started to work at experimental physics V, RUB, where she wants to explore electric field measurements in a Helium-fed RF-jet using the E-FISH technique.

Henrik van Impel, a physics graduate from Ruhr-University Bochum, joined the CRC 1316 in 2021, contributing to project A6. He completed both his bachelor`s and master`s theses within the project, specializing in the investigation of reactive species production and electric field properties in the micro-cavity plasma array. During his master`s thesis, he suc-

cessfully observed the directional electric field strength in a similar discharge geometry using the Stark shift and splitting of a helium line pair. With the start of his PhD this November, he continues to support the A6 project. His research aims to deepen the understanding of dielectric barrier discharges interacting with catalytic surfaces, contributing valuable insights to the ongoing progress of the CRC 1316.

Christian Busch studied physics at the Ruhr University Bochum with a focus on plasma physics. Since his bachelor's thesis, he has been a member of the Institute for Plasma and Atomic Physics (EP5), where he worked on the experimental characterization of a high-frequency RF discharge and GPU-accelerated Particle-In-Cell simulations. During his master's thesis, he joined the project A2, where he investigated the vibrational kinetics of CO_2 in CO_2/N_2 gas mixtures in a nanosecond pulsed discharge using quantum-cascade laser absorption spectroscopy. In October 2023, he started as a PhD student in the same project, where he will further study the kinetics of CO_2/N_2 mixtures using CARS to gain access also to the kinetics of N_2. Since ns-resolved measurements combined with a ns-pulsed discharge allow the separation of the different timescales of the vibrational kinetics, the various underlying processes can be studied in detail and kinetic models can be validated.

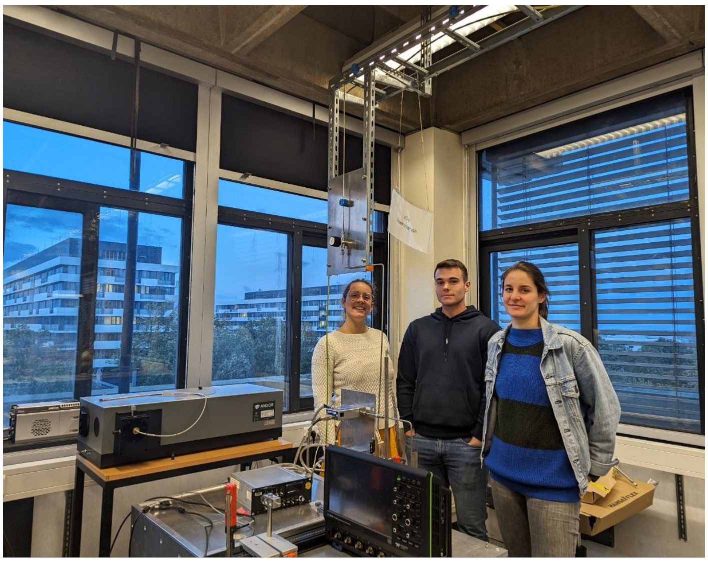
DAAD project success story continues

From the 24th of October to the 2nd of November Eloïse Mestre from GREMI in Orléans, France, was welcomed back to the group of Jun.-Prof. Judith Golda at the Ruhr University.

Her visit was focused on measuring the influence of CO_2 admixture on the gas temperature of a plasma jet expanding in open air generated by a DBD kHz source. It was her fourth and last visit of a fruitful cooperation. The trip was funded by a DAAD PROCOPE project in the framework of an international cooperation between RUB and GREMI.

The continuous work is finally rewarded with the first paper, which is now accepted by Plasma Processes and Polymers. It can be found under the title "Comparison of CO production and Escherichia coli inactivation by a kHz and a MHz plasma jet" by E. Mestre, I. Orel, D. Henze, L. Chauvet, S. Burhenn, S. Dozias, F. Brulé-Morabito, J. Golda, and C. Douat.

Lara Boeddinghaus, public relations



PAPER REPORT

Interactions Between Flow Fields Induced by Surface Dielectric Barrier Discharge Arrays

Non-thermal atmospheric pressure discharges are increasingly becoming a technology used in industrial applications. Dielectric barrier discharges (DBDs) are commonly used for tasks such as ozone generation, UV and VUV radiation generation, and pollution or surface treatment. Treating high gas flow rates requires a system with low flow resistance that can be scaled up. For gas treatment, Surface-DBDs (SDBDs) have the advantage of not being limited to the small gas gap between the electrodes.

In SDBDs, reactive species easily contact a larger gas volume, allowing for a more application-oriented approach. Our SDBD source from the "Chair of Applied Electrodynamics and Plasmatechnology" has already demonstrated significant potential for volatile organic compound abatement. Additionally, we have explored fundamental discharge parameters, including investigations into reactive species behavior.

Beyond the chemical perspective of gas treatment, SDBDs have been studied for decades for their influence on modifying gas stream dynamics. One of the primary goals has been to increase the efficiency of fluid machinery and reduce air resistance in planes. Considering this, we hypothesized that induced fluid dynamics should also affect our SDBD case.

To investigate the fluid dynamics of our SDBD, we utilized schlieren imaging and particle image velocimetry (PIV). Schlieren imaging provided insights into changes in the fluid's refractive index caused by the discharge itself or fluid movements. These results were compared with two-dimensional flow fields obtained through PIV. Varying the geometric complexity of our SDBDs produced more confined or open vortex structures by interacting with neighboring induced fluid flows.

Additionally, we conducted a simulation using nonPDPSIM to gain fundamental insights into these processes. To bridge the time-scales of discharge lifetime (ns) with relevant times for fluid dynamics (µs - ms), we applied an averaged local streamer with an average electrohydrodynamic (EHD) force to the fluid. Simulation results indicated that the EHD force primarily drove the induced fluid flow.

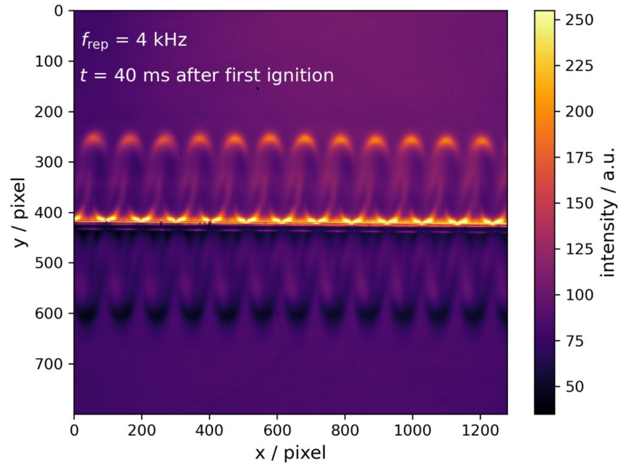


Figure 1: Exemplary lateral schlieren image of a SDBD source during the transient start phase.

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 induced fluid flows in overflowed cases and extend our simulations to calculate optimized grid geometry, as well as three-dimensional fluid flows.

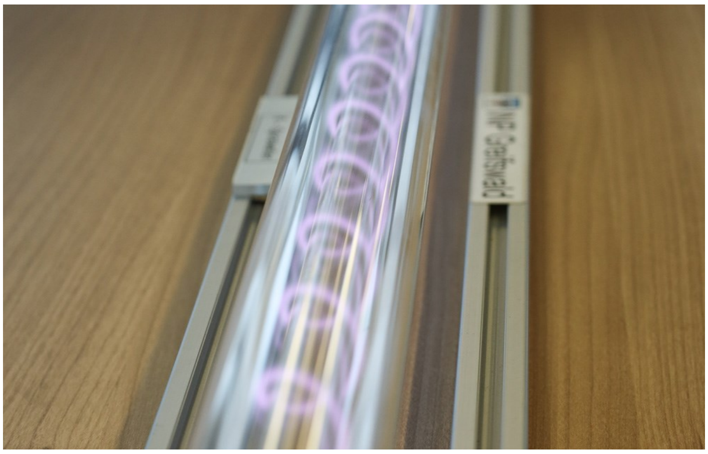
The paper was a collaboration between the projects A5 and A7. The paper can be found and cited as: A. Böddecker et al., "Interactions Between Flow Fields Induced by Surface Dielectric Barrier Discharge Arrays," Plasma Chem. Plasma Process. Springer Science and Business Media LLC, 2023. doi: 10.1007/s11090-023-10406-y.

View paper

Alexander Böddecker, project A7

PUBLIC RELATIONS

Graduation ceremony of the ET/IT faculty



In June, the Faculty of Electrical Engineering and Information Technology at the Ruhr University Bochum held its graduation ceremony and alumni festival at the same time under the motto 'A look into the past and the future'.

Both young visitors and former graduates were thrilled by the glowing gas spheres in the microwave and the rotating magnetized plasmas in a tube at our plasma stand.

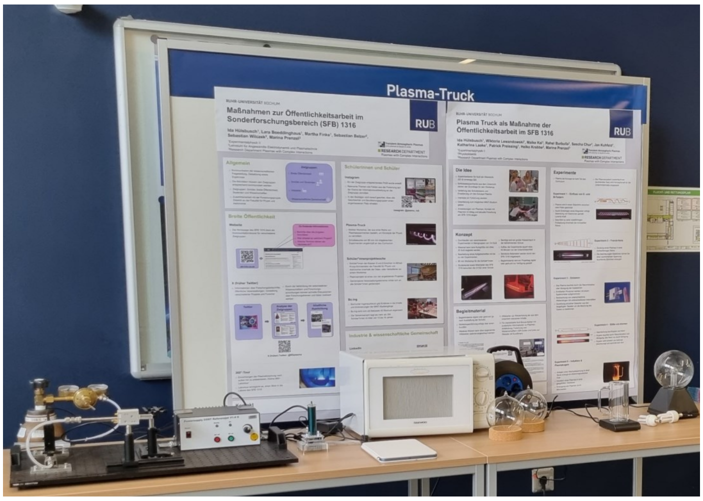
Sebastian Wilczek, project A5

Open the doors at the “Maustag”

The Faculty of Physics and Astronomy offered a wide range of activities for children on the yearly “Maustag”. We showed the children how to gild small toy animals with a sputter coater. They were also able to admire various plasmas and learn how a rainbow is formed. It was great fun for us and the children to go in search of the rainbow. At the end of the day, the children were allowed to take their chosen gold-plated animal home with them.

Lara Boeddinghaus, public relations

Conference for StuBos



On 15th November, the conference for the StuBos, the coordinators for career orientation at school, took place at the Ruhr University Bochum. The CRC 1316 presented the workshop “Plasma Truck” for students in 11th and 12th grade. This project is carried out in cooperation between AEPT and plasma physics.

The mobile plasma workshop visits a physics class at school. After watching a short movie and receiving basic knowledge about plasmas and their application, the students performed experiments in small groups.

Ida Hülsbusch, public relations

Two PhD defenses from the SFB-TR 87 and CRC 1316

Rahel Buschhaus has completed the successful defense of her PhD thesis in July 2023. Her research, conducted within project C7 of the SFB-TR 87, delved into surface processes involving the interaction of high-performance plasmas with HPPMS target surfaces and plastics. Titled "Ion-Induced Secondary Electron Emission of Plasma-Exposed Metals," Rahel's thesis represents a significant contribution to this field of study.

Tim Dirks — During my dissertation as part of the B8 project, I investigated various aspects of plasma-driven biocatalysis. Biocatalysis generally describes the use of purified enzymes to catalyze chemical reactions. It is gaining increasing importance as an alternative to conventional chemical synthesis, as enzymes are able to produce highly specific products with high selectivity under mild conditions.

The oxidation of non-activated C-H bonds in organic molecules is a reaction that is extremely difficult to accomplish using chemical methods and therefore represents an attractive field of application for biocatalysis. The fungal enzyme group of peroxygenases catalyzes exactly this oxyfunctionalization reaction with H_2O_2 as a co-substrate. Their application is currently limited, as an excess of H_2O_2 leads to their inactivation. Plasma-driven biocatalysis offers a method for generating H_2O_2 *in situ* with technical, non-thermal plasmas, which can then be used by the enzyme for substrate conversion.

The aim of my work was to address the previously identified challenges in order to optimize the efficiency of the process of plasma-driven biocatalysis. It is known that plasma treatment of enzymes leads to inactivation of enzymes due to modifications and degradation. The modification of the enzymes causes them to unfold, they lose their natural functions and they can clump together. The bacterial heat shock protein (Hsp33) prevents this clumping by binding unfolding proteins and we were able to show that this protein is activated by plasma treatments due to interactions with the plasma-generated species superoxide, singlet oxygen, and atomic oxygen.

Additionally, we identified immobilization as a promising protection strategy. The combination of the immobilization technique to protect the enzymes with plasma-driven biocatalysis allowed us

to transfer the plasma-driven biocatalysis to the application of a capillary plasma jet (provided by Steffen Schüttler from B11). In this way, we were able to significantly increase the efficiency of the process compared to earlier setups. In the future, the aim of the project will be to implement further enzymes in plasma-driven biocatalysis in order to broaden the scope of future applications. In addition, the focus will continue to be on further increasing the efficiency of plasma-driven biocatalysis. For this, we will also evaluate new reactor design concepts.

Project B14: Modeling of solvated electrons

A new project (B14) is funded within the CRC 1316. The project "The Solvated Electron at the Electrified Solid/Liquid Interface: Structure and Dynamics from Ab Initio Molecular Dynamics Simulations," led by Marialore Sulpizi, investigates solvated electrons that arise through interactions with plasmas in liquids. This research is pivotal for understanding interface processes at the solid-liquid interface and plasma-induced chemistry within liquids.

versity of Ulm. Moreover, it will provide essential support to various experimental projects within the B area, including B5, B7, B12, and B13, all of which investigate the interaction of plasma with solids.

The project's results will be seamlessly integrated into the chemistry models of liquids in B5 and B11, as well as the plasma excitation model in B7. This integration aims to provide a comprehensive ex-

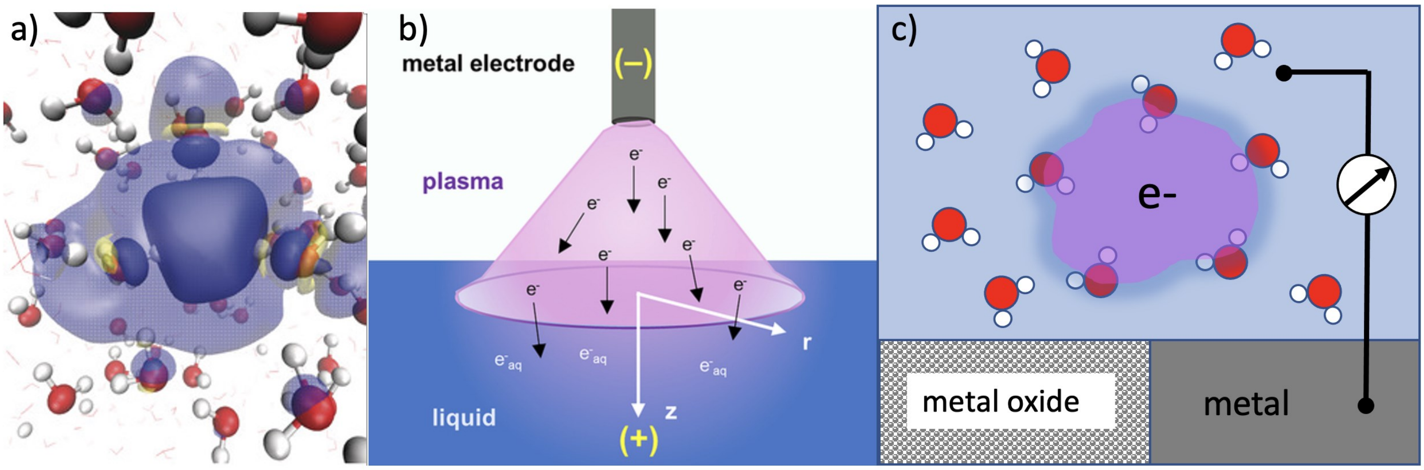


Figure 1: (a) Structure of the hydrated electron from [1]. The water molecules form cavity around the electron. Blue: positive spin density; yellow: negative spin density. (b) A schematic of the plasma-liquid interface as depicted in [2]. At a negatively electrode the electrons produced in the plasma are transferred to the liquid where they become solvated. (c) A scheme of the main idea behind this proposal: the structure of the solvated electron will be investigated at the electrified liquid/ solid interface to mimic plasma physics conditions. The solid surface may be either a metal, of a metal oxide (depending on the experimental conditions).

Solvated electrons, extensively studied in low electric fields as seen in electrolysis, present distinct challenges when induced by plasmas. In plasma systems, where voltages can reach several kilovolts, the high electric fields demand specialized attention within the modeling framework.

Project B14 will delve into uncharted territory by addressing the impact of solvated electrons through three consecutive steps and work packages. The project's findings will contribute to the microscopic modeling of the solid/liquid interface conducted by project B4, led by Jacob at the Uni-

planation for the experimental observations in these projects.

Project B14's focus on the modeling of solvated electrons induced by plasmas in liquids marks a significant advancement in our understanding of interface processes and plasma-induced chemistry.

Marialore Sulpizi, project B14

[1] Wilhelm J., VandeVondele, J. and Rybkin, V. V., Angew. Chem. Int. Ed. 58, 3890–3893, 2019.

[2] Delgado, HE, Brown, GH, Bartels, DM, Rumbach, P, Go DB, Journal of Applied Physics 129, 083303, 2021, doi: 10.1063/5.0040163

ICPIG

The International Conference on Phenomena in Ionized Gases (ICPIG) had been held in Egmond aan Zee and was a great success for the participants from CRC 1316.

During the conference, numerous high quality presentations were given, covering a wide range of topics in the field of ionized gases. In addition, the ICPIG offered participants the opportunity to network in informal discussions and networking sessions.

Sebastian Wilczek, project A5

CRC 1316 PhD students at Plasma School

Once again this year, five (prospective) doctoral students from the SFB travelled to Bad Honnef for the 26th International Plasma School. In addition to a beautiful view from the Drachenfels (see photo), a tight programme of workshops and lectures provided a comprehensive introduction to the fundamentals of low-temperature plasma physics.

This was rounded off by an evening poster session on current research topics and a talk about the history of plasma physics and ensured a lively exchange between the students who had travelled to Bad Honnef from all over the world.

On the subsequent two-day masterclass, the knowledge already acquired in the field of "Atmospheric pressure plasmas and their applications" was further deepened.

Henrik van Impel & Robin Labenski, project A6

76th Annual Gaseous Electronics Conference

Several members of the CRC1316 joined the GEC2023, hosted at the University of Michigan.

With a total of 23 contributions, the university showcased advancements in semiconductor manufacturing, innovations in gas conversion and environmental technology, and deepened our understanding of plasma science.

The GEC2023 conference served as an excellent platform for the CRC members to engage in knowledge exchange, collaboration, and networking within the global scientific community.

Sebastian Belzer, public relations

69th International Symposium of the Americam Vacuum Society

Judith Golda represented the CRC 1316 at the AVS 69th International Symposium & Exhibition from November 5-10, 2023, in Portland, Oregon.

Her invited talk was about “Fundamentals of atmospheric pressure discharges for plasma catalytic applications”. In her talk, Jun.-Prof. Judith Golda immersed the audience in the pivotal realm of atmospheric pressure discharges and their profound role in plasma catalysis.

Navigating the complexities of atmospheric pressure discharges, Judith Golda underscored their transformative potential, especially in catalytic processes.

Judith Golda, projects A6, B2, and B11

25th International Symposium on Plasma Chemistry

I had the opportunity to attend ISPC 25 in Kyoto, Japan. This was my second visit to Japan for a conference, and I wholeheartedly recommend this kind country to all of you. I had the chance to connect with scientists from all around the globe. The amount of research presented on atmospheric pressure discharges was substantial and equally interesting. Each day, new findings related to gas treatment and environmental applications, which are in a rising sector, were discussed. The primary focus was on CO_2 splitting and methane conversion.

I held a talk about the “Analysis of the flow field induced by a surface dielectric barrier discharge designed for air pollution remediation”. The audience's reaction to my presentation was very positive.

I connected with several students who would like to visit our institute for collaborations. What stood out to me was the interest in my research topic from scientists with a background in medical and biological research. This interaction not only provided fresh perspectives for my ongoing research but also inspired ideas for future studies and grant proposals. The visit was funded by the travel funds of CRC 1316.

Alexander Böddecker, project A7

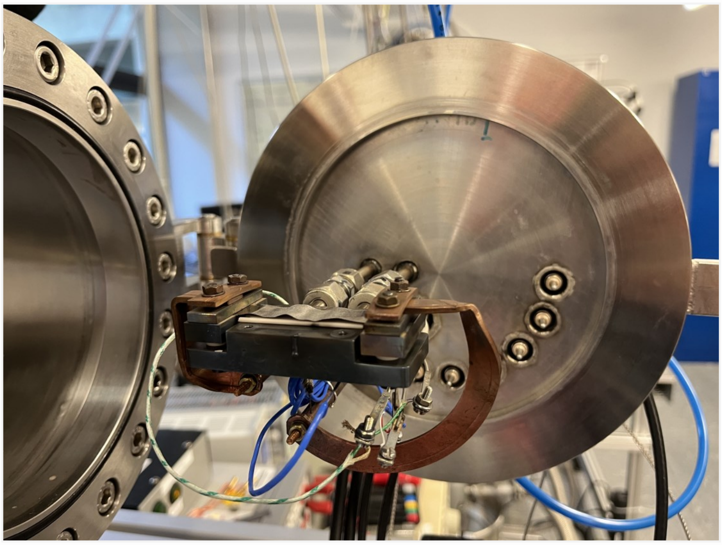
Thanks to Dr. Sebastian Burhenn

Huge thanks to Dr. Sebastian Burhenn who took marvelous photos of the physicists of the CRC 1316 at RUB.

As a professional hobby photographer, he brought his equipment to capture wonderful images for our websites. Since we are experimental physicists, the photo session took place in a laboratory.
Can you spot a photo he took in this newsletter?

Martha Finke, public relations

IMPRESSIONS



IMPRESSUM

Public relations CRC 1316

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