Hakone XVIII

18th INTERNATIONAL SYMPOSIUM ON HIGH PRESSURE LOW TEMPERATURE PLASMA CHEMISTRY

Scientific Program & Book of Abstracts

Abano Terme (Padova), Italy, September 1 - 6, 2024

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Preface

Dear Colleagues,

on behalf of the International Scientific Committee and of the Local Organizing Committee, we are pleased to welcome you in Abano Terme during September 1 - 6, 2024, to attend Hakone XVIII, the *18th International Symposium on High Pressure Low Temperature Plasma Chemistry*. The event is organized by the Department of Chemical Sciences of the University of Padova, with the collaboration of the Department of Physics and Astronomy of the same University.

The Hakone symposia are biannual international conferences, started in Hakone (Japan) in 1987 with the intent to gather scientists interested in fundamental aspects and applications of non-thermal plasmas at atmospheric pressure. Sixteen editions followed, organized in different continents and countries including Italy in 2004. It is for us a special pleasure to host the return to Italy of the Hakone community exactly twenty years after Hakone IX which was organized in Padova in 2004 by Prof.s Massimo Rea and Cristina Paradisi.

Over the past 30 years Hakone symposia have provided a constructive, challenging and friendly environment for scientists and researchers at the forefront of plasma science to discuss and share knowledge and perspectives. In doing so Hakone conferences have thus supported and strongly contributed to the advancement and diffusion of plasma science.

We are confident that Hakone XVIII will succeed in continuing this tradition and offer an interactive platform for researchers of different backgrounds (chemistry, physics, engineering, material sciences, biology, medicine). Such interdisciplinarity is now strongly needed to meet the demands of plasma science, which is becoming more and more transversal and pervasive. It will also hopefully promote opportunities for establishing new collaborations and research networks. Another important goal we set to ourselves in organizing Hakone XVIII was to reinforce the engagement of young scientists (students and post-docs) and that of researchers from industry. Accordingly, the program offers dedicated sessions for oral flash presentations of posters and for technical contributions by industrial researchers. Moreover, with the support of Springer, we have established two Young Scientists Award for best contributions, one for oral and one for poster presentations given by Student presenting Authors.

This book collects the abstracts of the scientific contributions presented at Hakone XVIII, authored by researchers from 24 different countries and comprising 6 invited lectures, including the Ulrich Kogelschatz Lecture Award, 57 oral contributions, 37 posters and 4 technical communications. The collection of abstracts is also available in electronic format on a USB stick given to each participant.

Support by the University of Padova and by the sponsors mentioned in the next pages is gratefully acknowledged. We also acknowledge the contribution and work of our post-docs and students.

On behalf of the LOC, we wish you all a fruitful and challenging professional experience at Hakone XVIII and a pleasant stay in Abano Terme.

Ester Marotta and Cristina Paradisi
Chair and Honorary Chair of Hakone XVIII

Padova, August 25, 2024

Committees

International Scientific Committee

- Ronny Brandenburg, Germany
- Tomáš Hoder, Czech Republic
- Indrek Jõgi, Estonia
- Štefan Matejčík, Slovakia
- Nicolas Naudé, France
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- Fumiyoshi Tochikubo, Japan Kuniko Urashima, NISTEP, Japan
- Keping Yan, Zhejiang University, China
- T. Zhang, Dalian Maritime University, China

Local Organizing Committee

Ester Marotta, Chair, Department of Chemical Sciences, University of Padova
Cristina Paradisi, Honorary Chair, senior scientist, Department of Chemical Sciences, University of Padova
Alessandro Patelli, Department of Physics and Astronomy, University of Padova
Enzo Menna, Department of Chemical Sciences, University of Padova
Giulia Tomei, Department of Chemical Sciences, University of Padova
Mubbshir Saleem, Department of Chemical Sciences, University of Padova

Special thanks to

- Martina Varotto, University of Padova, Italy
- Alberto Miotto, University of Padova, Italy
- Mattia Negrisolo, University of Padova, Italy
- Riccardo Fiorotto, University of Padova, Italy
- Ehsan Shakerinasab, University of Padova, Italy

Supporters and sponsors

General information

Hakone XVIII, the *18th International Symposium on High Pressure Low Temperature Plasma Chemistry* is organized by the Department of Chemical Sciences of the University of Padova, with the collaboration of the Department of Physics and Astronomy of the same University, in Abano Terme (Padova), Italy, during September 1 - 6, 2024.
Hakone conferences bring together scientists and engineers from academia and industry working on fundamental and applied aspects of high pressure and low temperature plasma chemistry. The first conference took place in Hakone (Japan) in 1987 and was followed by sixteen editions organized all over the world, among which Padova in 2004. Thus, with Hakone XVIII, the Hakone community is returning to the University of Padova after 20 years! The University of Padova was established in 1222. Defending freedom of thought in study and teaching became a distinctive feature which today lives on in the University motto: Universa Universis Patavina Libertas.
Aim of the symposium is the advancement of knowledge in plasma science and technology through the promotion of constructive interactions among scientists having different backgrounds but sharing the common interest in developing plasma-based technologies, in particular for environmental protection and improvement of the quality of life. The fields covered in Hakone XVIII range from plasma fundamentals and electrical/optical diagnostics, to applications dealing with energy issues, fuel reforming, CO_2 conversion and nitrogen fixation, to advanced oxidation and reduction processes for water treatment and environmental protection, to biomedical applications, to material science, to modelling. The five-day format adopted, the number of participants and the venue of the symposium will provide excellent opportunities for constructive debate and exchange of knowledge and information both during scientific sessions and informal discussions.
Scientific contributions will be presented in oral and poster sessions. Authors of poster contributions will have the opportunity to introduce their work in flash oral presentation sessions. There will also be a session for technical contributions by industrial researchers. Following a tradition initiated in 2016, the Ulrich Kogelschatz Lecture Award (UKLA) will be presented during the opening ceremony of Hakone XVIII. In addition, two Young Scientists Award will be assigned for best contributions, one for oral and one for poster presentations given by Student presenting Authors.

Topics

- Fundamentals, Modelling and Diagnostics
- Environmental and Energy Applications
- Biomedical Applications
- Surface and Material Science and Technology
- Miscellaneous

Venue and accommodation

Abano Terme is a spa resort located about 50 km west of Venezia and about 10 km southwest of Padova. It is part of Terme ("Spas") Euganee, internationally renowned for their hot thermal waters appreciated since the times of ancient Roma. The beautiful Euganean Hills (Colli Euganei) of volcanic origin are located nearby.
Accommodation, lunches and all scientific activities will be at the Alexander Palace Hotel, a major structure fully equipped for conferences and wellness (address: via Martiri d'Ungheria 24, Abano Terme, Italy).

Social events

On Sunday September 1, after registration, we will have the pleasure to welcome you all with a reception party at the Alexander Palace Hotel from 18:30 to 20:00. In the afternoon of Wednesday September 4, we are inviting you to the conference excursion which will take us to visit Villa Selvatico on the Euganean Hills and will include a small toast with refreshments. Finally, on Thursday September 5, you are invited to the conference Gala dinner at the restaurant Euganeus 2000 in Cervarese Santa Croce (PD). Practical details will be given during the conference.

Information for Authors presenting oral and poster contributions

Oral contributions

- Please take note of the following time constraints and make sure to respect them (we have a very dense program!):
    - Invited lectures (40 min): 30 min for presentation + 10 min for discussion
    - Oral communications (20 min): 15 min for presentation + 5 min for discussion
- Please submit the file (.ppt or .pdf) with your presentation at the registration desk when you register or, at the latest, at the beginning of the first morning or first afternoon session of the day of your lecture.
- It will not be possible to use your own PC.

Poster contributions

Poster contributions will have excellent exposure and opportunities for discussion. Each poster will be introduced by a brief oral presentation by the presenting Author in the assigned Flash Presentations session and will remain posted in the Poster Hall, adjacent to the Conference Hall, during the whole duration of the conference. Therefore, contributing Authors will introduce their poster in the assigned Flash Presentations session and present it during the assigned Poster Session, but will also have the opportunity to discuss with interested participants in front of their poster at any other convenient time during the conference.

Poster oral flash presentation:

Please prepare two slides, one with the poster identification info (title, Authors, institutions etc), the other with highlights on the contents (the research motivation&goals/novelty/take away message/… any of your choice). Be prepared to present these two slides in 1.5 min. and to raise interest and curiosity in the audience about your poster.

- Please submit the file (.ppt or .pdf) with your presentation at the registration desk when you register or, at the latest, at the beginning of the first morning or first afternoon session of the day of your lecture.
- It will not be possible to use your own PC.

Poster presentation:

Poster stands are vertical. Poster size: 90 cm (width) x 120 cm (height).

Contributing Authors should post their poster on Monday at the beginning of the conference in the Poster Hall which is adjacent to the Conference Hall and remove them at the end of the conference. Adhesive tape and pins will be available at the conference desk.

"Young Scientist Award"

Young Scientist awards will be presented to two Student presenting Authors, one for best oral and one for best poster communications, respectively. The awardees will be selected by a committee nominated by the Hakone ISC. During the closing ceremony they will receive each a certificate and a 150 euros worth book voucher gift kindly donated by Springer, which is sponsoring the event.

Contact Information

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Scientific program

	Sunday, Sept 1st	Monday, Sept 2nd	Tuesday, Sept 3rd	Wednesday, Sept 4th	Thursday, Sept 5th	Friday, Sept 6th
8:30-8:50		Registration	I-01 Shang	I-03 Sretenovic	I-04 Bilek	I-05 Malinowski
8:50-9:10		Opening cerimony				
9:10-9:30		UKLA Dilecce	O-12 Machala	O-27 Dap	O-36 Clack	O-51 Jõgi
9:30-9:50			O-13 Magureanu	O-28 Sasaki	O-37 Tampieri	O-52 Tochikubo
9:50-10:10		O-01 Fridman	O-14 Kushner	O-29 Krös	O-38 Šrámková	O-53 Popoli
10:10-10:30		O-02 Yan	O-15 Saleem	O-30 Šimek	O-39 Čechová	O-54 Biondo
10:30-11:00		Coffee break	Coffee break	Coffee break	Coffee break	Coffee break
11:00-11:20		O-03 Cimerman	O-16 Sales	O-31 Wijnants	O-40 Stryczewska	O-55 Mohsenimehr
11:20-11:40		O-04 Hecimovic	O-17 Tomei	O-32 Khazem	O-41 Watanabe	O-56 Bonaventura
11:40-12:00		O-05 Schiorlin	O-18 Hamdan	O-33 van Impel	O-42 Profili	COST report - Pawlat
12:00-12:20		O-06 Vermile	O-19 Bilea	O-34 Moravský	O-43 Höft	Closing remarks
12:20-12:40		O-07 Chen	Flash Presentations	O-35 Tarasenka	Flash Presentations	
12:40-14:20		Lunch	Lunch	Lunch	Lunch	Lunch
14:20-14:40	Registration	Flash Presentations	I-02 Sobota	Excursion	O-44 Kocik	
14:40-15:00		T-01 Plasmatreat			O-45 Patelli	
15:00-15:20		T-02 Tecnosida	O-20 Obradovic		O-46 Pazderka	
15:20-15:40		T-03 Impedans	O-21 Bröcker		O-47 Guo Yulin	
15:40-16:00		T0-4 Nadir	O-22 Krumpolec		O-48 Haton	
16:00-16:30		Coffee break	Coffee break		Coffee break	
16:30-16:50		O-08 Kim	O-23 Perdrau		O-49 Giotis	
16:50-17:10		O-09 Abd-Allah	O-24 Galmiz		O-50 Guo Yihao	
17:10-17:30		O-10 Betz	O-25 Švandová		Poster Session P24 - P38	
17:30-17:50		O-11 Spadoni	O-26 Polášková			
17:50-18:30		Poster Session P01 - P12	Poster Session P13 - P23			
18:30-19:00	Welcome party					
19:00-19:30					Gala Dinner	
19:30-20:00						
20:00-20:30						
20:30-21:00						
21:00-....			Int. Scientific Committee meeting			

September 1, 2024, Sunday

14:30 - 18:30	Registration
18:30 - 20:00	Welcome Party

September 2, 2024, Monday

08:50 - 09:10	Opening ceremony. Presentation of Ulrich Kogelschatz Lecture Award

Chair: Ronny Brandenburg

09:10 – 09:50	**Ulrich Kogelschatz Lecture Award** Giorgio Dilecce *Optical diagnostics of plasma chemistry*
09:50 - 10:10	**O-01** Alex Fridman *Investigating changes in physical properties of water as result of non-thermal plasma interaction (surface tension, viscosity and contact angles)*
10:10 - 10:30	**O-02** Keping Yan *Industrial dielectric barrier discharge plasma systems*
10:30 - 11:00	Coffee break

Chair: Fumiyoshi Tochikubo

11:00 - 11:20	**O-03** Richard Cimerman *CO_2 conversion by nonthermal plasma: dielectric barrier discharge vs. transient spark*
11:20 - 11:40	**O-04** Ante Hecimovic *Atmospheric pressure microwave plasmas for CO_2 conversion and CH_4 pyrolysis*
11:40 - 12:00	**O-05** Milko Schiorlin *Plane parallel barrier discharge for carbon dioxide splitting: reactor optimization*
12:00 - 12:20	**O-06** Valeria Vermile *Supported metal oxide materials for plasma-catalytic dry reforming of methane*
12:20 - 12:40	**O-07** Haodong Chen *Kinetic study of CO_2 reforming of dimethyl ether in a nanosecond pulsed discharge*

12:40 – 14:20 Lunch

Chair: Keping Yan

14:20 - 14:40 **Flash presentations**
Posters **P-01** – **P-12**

Technical Contributions

14:40 - 15:00 **T-01** Nicolò Frezza, Plasmatreat
Atmospheric Pressure Plasma Coating deposition of Functionalized thin films as green alternatives for Adhesion Promotion process

15:00 - 15:20 **T-02** Davide Pasini, Tecnosida
Odor mitigation with cold plasma in industrial emission sources

15:20 - 15:40 **T-03** Daniel Simpson, Impedans
Characterization of a Pulsed DC kHz Helium Jet vs different powers and flow rates, and Density Spatial Analysis of the Jet Source

15:40 - 16:00 **T-04** Paolo Scopece, Nadir
Nadir Dual Frequency Plasma: a versatile device for functional coatings deposition for a wide range applications, from biomedical to green hydrogen production

16:00 - 16:30 Coffee break

Chair: Sander Nijdam

16:30 - 16:50 **O-08** Hyun-Ha Kim
Sustainable NOx formation using high-frequency spark discharge plasma

16:50 - 17:10 **O-09** Zaenab Abd-Allah
The effect of different photocatalysts on nitrogen and oxygen chemistry in a dielectric barrier discharge plasma

17:10 - 17:30 **O-10** Meret Leonie Betz
Nitrogenation of alkanes by dielectric-barrier post-discharges

17:30 - 17:50 **O-11** Francesco Spadoni
Plasma Catalysis for Nitrogen Fixation to Ammonia

17:50 - 19:00 **Poster Session 1** - Posters **P-01** to **P-12**

P-01 Rodrigo Antunes
Plasma-assisted ammonia synthesis in a dielectric barrier discharge reactor at various operating conditions

P-02 Jiří Fujera
Comparative study of the efficacy of nitrogen fixation by various atmospheric-pressure plasma sources

P-03 Ronny Brandenburg
Non-thermal plasma induced CO generation from CO_2 studied by operando-DRIFTS: Experimental design and first results

P-04 Madhuwanthi Buddhadasa
CO_2 conversion in a packed-bed cylindrical dielectric barrier discharge

P-05 Aftab Javaheri
Hydrogen production from decomposition of ethanol using a non-self-sustained plasma discharge at atmospheric pressure: hydrogen selectivity and energy efficiency evaluation

P-06 Zdenko Machala
Non-thermal plasma with photocatalysis for bacteria decontamination and VOC removal from indoor air

P-07 Gokul Selvaraj
NOx removal by discharge in honeycomb monolith

P-08 Zitong Yang
Degradation of benzene by micro-discharge plasma formed in Mn-Ce loaded porous ceramics

P-09 Nikola Cvetanović
The influence of gas flow rate on a helium DBD via the impurity level

P-10 Ramin Mehrabifard
Chemical effect of Ultraviolet radiation on plasma activated water by transient spark plasma

P-11 Zdeněk Navrátil
Optical emission spectroscopy of DBD plasma and diffusion flame atomizers

P-12 Naoki Osawa
Observation of spatiotemporal distribution of surface charge density on alumina barrier during atmospheric pressure Townsend discharge in air

September 3, 2024, Tuesday

Chair: Alex Fridman

08:30 - 09:10	**I-01** Kefeng Shang *Hybrid discharge plasma technologies for water decontamination*
09:10 - 09:30	**O-12** Zdenko Machala *Selective production of reactive oxygen and nitrogen species in plasma-activated water*
09:30 - 9:50	**O-13** Monica Magureanu *Plasma degradation of complex mixtures of antibiotics in water*
9:50 - 10:10	**O-14** Mark J. Kushner *Consequences of direct electron impact onto liquid surfaces*
10:10 - 10:30	**O-15** Mubbshir Saleem *Towards holistic wastewater treatment using activated carbon/zeolite coupled atmospheric plasma system*
10:30 - 11:00	Coffee break

Chair: Indrek Jõgi

11:00 - 11:20	**O-16** Christopher M. Sales *Application of gliding arc and dielectric barrier discharges on the treatment of poly- and perfluoroalkyl substances (PFAS)*
11:20 - 11:40	**O-17** Giulia Tomei *Purification of PFAS-contaminated groundwater by treatment with a RAdial discharge Plasma (RAP) reactor: the fate of degradation products*
11:40 - 12:00	**O-18** Ahmad Hamdan *Streamer discharge in air over a liquid surface: influence of permittivity and conductivity*
12:00 - 12:20	**O-19** Florin Bilea *Exploring the degradation intermediates of sulfamethoxazole during plasma treatment*
12:20 - 12:40	**Flash presentations** Posters **P-13** – **P-24**
12:40 - 14.20	Lunch

Chair: Ahmad Hamdan

14:20 - 15:00	**I-02** Ana Sobota *The interaction of atmospheric pressure plasmas with targets*
15:00 - 15:20	**O-20** Bratislav Obradović *DBD plasma treatment as a sustainable method for enhancing the wettability of jute fabrics*
15:20 - 15:40	**O-21** Lars Bröcker *Microdot-wise plasma polymer deposition from APGD-type DBDs*
15:40 - 16:00	**O-22** Richard Krumpolec *Fast low-temperature plasma-triggered self-propagation reduction-exfoliation process of graphene oxide materials*
16:00 - 16:30	Coffee break

Chair: Nicolas Naudé

16:30 - 16:50	**O-23** Alexandre Perdrau *Synthesis of gold/polymer thin films in Ar and Ar/NH_3 DBDs*
16:50 - 17:10	**O-24** Oleksandr Galmiz *Investigating changes in the chemical composition of liquid during polymer tube processing by SDBD*
17:10 - 17:30	**O-25** Lucia Švandová *Properties of Cr-doped Al_2O_3 as a dielectric barrier layer for atmospheric pressure discharges*
17:30 - 17:50	**O-26** Kateřina Polášková *Influence of edge proximity on uniformity of atmospheric pressure plasma slit jet treatment of polypropylene*
17:50 - 19:00	**Poster Session 2** - Posters **P-13** to **P-23** **P-13** Vesna V. Kovačević *Degradation of propranolol by water falling film DBD reactor in different atmospheres* **P-14** Alberto Miotto *Study of the effect of volume in the treatment of solutions containing organic contaminants in a RAdial discharge Plasma (RAP) reactor*

P-15 Martina Varotto
Investigation of atmospheric plasma treatments for the degradation of perfluorinated carboxylic acids adsorbed on granular activated carbons

P-16 Mattia Negrisolo
Development of a plasma technology for the regeneration of granular activated carbon (GAC) containing PFAS

P-17 Martina Varotto
Oxidation of Microcystin-LR by air atmospheric plasma: process efficiency and degradation products

P-18 Oleksandr Boiko
Recent developments in plasma processing of functional materials for electronic and energetic sectors

P-19 Alex Destrieux
On the use of volume dielectric barrier discharge for the treatment of transparent electrode for organic photovoltaics

P-20 Sandra Ďurčányová
Exploring the effect of key parameters in atmospheric-pressure plasma polymerization for layer deposition

P-21 Jana Kšanová
Nonthermal plasma regeneration of deactivated catalysts

P-22 Elène Bizeray
Synthesis of metal/polymer nanocomposite thin film by using an aerosol-assisted atmospheric pressure plasma process

P-23 Nikolai Tarasenko
Plasma-activated electrolysis synthesis and properties of Cu/Zn oxides nanostructures for sensing applications

September 4, 2024, Wednesday

Chair: Mark Kushner

08:30 - 09:10 **I-03** Goran B. Sretenović
Spectral line shape analysis as a tool for the diagnostics of atmospheric pressure discharge

09:10 - 09:30	**O-27** Simon Dap *Characterization of filamentary and diffuse DBD in CO_2 by optical emission spectroscopy and in-situ FTIR spectroscopy*
09:30 - 09:50	**O-28** Koichi Sasaki *Correlation of ammonia synthesis rate with fluxes of atomic nitrogen and molecular nitrogen at vibrational excited states generated by an atmospheric-pressure plasma jet*
09:50 - 10:10	**O-29** Levin Krös *Spatio-temporal density distribution of all four $Ar^*(3p^54s)$ states in a pulsed-operated dielectric barrier discharge at elevated pressures*
10:10 - 10:30	**O-30** Milan Šimek *Temporally and spatially resolved radiation characteristics observed at the initial stage of nanosecond discharge in liquid water*
10:30 - 11:00	Coffee break

Chair: Henryka Danuta Stryczewska

11:00 - 11:20	**O-31** Cedric Wijnants *Heavy hydrocarbon conversion in nanosecond pulsed discharges*
11:20 - 11:40	**O-32** Fatima Khazem *Optical diagnostic of an Ar microwave plasma jet expanding in ambient air using hyperspectral imaging*
11:40 - 12:00	**O-33** Henrik van Impel *Utilization of the Stark effect in micro-scaled DBDs for the determination of fundamental plasma parameters*
12:00 - 12:20	**O-34** Ladislav Moravský *Study of ion formation of alkanes in atmospheric pressure by ion mobility-mass spectrometry (IM-MS)*
12:20 - 12:40	**O-35** Natalie Tarasenka *Plasma-driven chemistry in liquid microdroplets as a tool for the perovskite nanoparticles synthesis*
12:40 – 14:20	Lunch
14:20 - 19:00	Conference excursion

September 5, 2024, Thursday

Chair: Štefan Matejčík

08:30 - 09:10	**I-04** Marcela M. M. Bilek *Low temperature plasma processes for constructing bioinstructive platforms for cell culture and tissue-integration*
09:10 - 9:30	**O-36** Herek L. Clack *Inferring viral aerosol protein damage from non-thermal plasma exposure using a Wide-Band Integrated Bioaerosol Spectrometer (WIBS)*
09:30 - 09:50	**O-37** Francesco Tampieri *Hydrogels as models to quantify the distribution and penetration of plasma-generated reactive species on tissues*
09:50- 10:10	**O-38** Petra Šrámková *Improvement of seeds germination parameters by plasma treatment and investigation of the reached characteristics during their long-term storage*
10:10 - 10:30	**O-39** Ludmila Čechová *Plasma activated water applications in agriculture*
10:30 - 11:00	Coffee break

Chair: Hyun-Ha Kim

11:00 - 11:20	**O-40** Henryka Danuta Stryczewska *Review of Power Supply Systems of Plasma Reactors with DBD, GAD and APPJ*
11:20 - 11:40	**O-41** Kazuki Watanabe *Effect of residual surface charge on generating the atmospheric pressure townsend discharge in air*
11:40 - 12:00	**O-42** Jacopo Profili *Can electrical parameters in nitrogen discharges at atmospheric pressure be used to study physico-chemical modifications in real time?*
12:00 - 12:20	**O-43** Hans Höft *Filament interaction in pulsed dielectric barrier discharges*
12:20 - 12:40	**Flash presentations** Posters **P-24** – **P-37**

12:40 - 14:20 Lunch

Chair: Naoki Osawa

14:20 - 14:40	**O-44** Marek Kocik *Agglomeration effect of bipolar-charged airborne particles induced by a dielectric barrier discharge (DBD)*
14:40 - 15:00	**O-45** Alessandro Patelli *Micro-second pulse and RF coupling in an atmospheric pressure plasma jet*
15:00 - 15:20	**O-46** Michal Pazderka *Coplanar dielectric barrier discharge at MHz frequencies in Argon and Argon/Nitrogen mixture*
15:20 - 15:40	**O-47** Yulin Guo *Investigation of the diffuse nanosecond discharge characteristics under double pulse experiments in different N_2/O_2 mixtures*
15:40 - 16:00	**O-48** Julie Haton *Diffuse DBD memory effect in air: surface and volume mechanisms*

16:00 - 16:30 Coffee break

Chair: Naoki Osawa

16:30 - 16:50	**O-49** Konstantinos Giotis *Peculiarities of Lissajous Q-V diagrams during power measurements in pulsed SDBDs*
16:50 - 17:10	**O-50** Yihao Guo *Electric field measurement of single channel streamers by E-FISH*
17:10 - 18:20	**Poster Session 3** - Posters **P-25** to **P-37**
	P-24 Kirara Yamanaka *Sterilization properties of surface materials of spacecraft by low-pressure and RF water plasma contributing to planetary protection*
	P-25 Shameem Ahmed *Effects on Physicochemical Properties of Mung Bean by Oxygen Plasma Irradiation at Different Pressure on Seeds*
	P-26 Sandra Ďurčányová *The possibilities of using cold atmospheric pressure plasma in agriculture comparison of laboratory-scale plasma source and its modified version for industrial use*

P-27 Saori Kodaka
Activation of macrophage-T cell immune system using atmospheric pressure oxygen plasma

P-28 Hinako Nakamura
Cytokine release characteristics of T cells after plasma irradiation in liquid using a porous membrane plasma generator

P-29 Joanna Pawlat
Plasma treatment of freshly squeezed carrot juice

P-30 Daiki Takeshita
Induction of differentiation and cytokine release of EL4 T-cell by barrier discharge oxygen plasma

P-31 Shin-ichi Aoqui
Improved working gas utilization by Gliding Arc Discharge with twisted electrodes

P-32 Riccardo Fiorotto
Electrodynamic flow induced in a liquid by a dual frequency APPJ

P-33 Sayma Khanom
Removal of lead from water by non-thermal oxygen plasma treatment

P-34 Grzegorz Komarzyniec
Effect of plasma gas parameters on the efficiency of a three-phase plasma reactor with gliding arc discharge

P-35 Richard Krumpolec
New linear plasma jet system based on Diffuse Coplanar Surface Barrier Discharge

P-36 Piotr Krupski
Center tapped transformer for Glidarc plasma technique

P-37 Hugo Lagarrigue
Exploring the influence of experimental method and apparatus on energy measurement in Partial Discharge or Monofilament DBD at atmospheric pressure in air

19:00 - 23:00 Gala dinner

September 6, 2024, Friday

Chair: Milan Šimek

08:30 - 09:10	**I-05** Szymon Malinowski *Plasma applications in analytical chemistry*
09:10 - 9:30	**O-51** Indrek Jõgi *The characterization of an RF Ar plasma jet operating in controlled O_2, N_2 or air ambient gas*
09:30 - 09:50	**O-52** Fumiyoshi Tochikubo *Numerical study on the effect of negative corona discharge on droplet emission from Taylor cone*
09:50- 10:10	**O-53** Arturo Popoli *MERLINO – An efficient 0D solver for non-thermal plasma simulations*
10:10 - 10:30	**O-54** Omar Biondo *Multi-temperature model for CO_2 non-equilibrium plasmas*
10:30 - 11:00	Coffee break

Chair: Monica Magureanu

11:00 - 11:20	**O-55** Soad Mohsenimehr *Flow induced by Surface Dielectric Barrier Discharge (sDBD) for plasma conversion*
11:20 - 11:40	**O-56** Zdeněk Bonaventura *Discrete Ordinates method for capturing photoionization shadows in air streamer simulations*
11:40 - 12:00	**COST Report** Joana Pawlat PlAgri COST Action 19110 – Plasma applications for smart and sustainable agriculture
12:00 - 12:40	**Closing Remarks and Announcement for Hakone XIX**
12:40	Lunch

Abstracts

Invited lectures

UKLA - ULRICH KOGELSCHATZ LECTURE AWARD

Optical diagnostics of plasma chemistry

Giorgio Dilecce
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Plasma chemistry (PC) is an inter/multi-disciplinary science. Plasma diagnostics is no less. PC is also applied science, then it is expected to feed industry with technologically sound devices. This implies a deep knowledge of non-equilibriun discharges, in which entangled physical and chemical phenomena contribute to the performance. The knowledge of discharge parameters like the reduced electric field, the temperature, the density of charged particles, is as important as that of chemical kinetics of transient species and stable products. In the last two-three decades, when atmospheric-pressure (ATP) processes have attracted much research efforts, optical diagnostics have seen a growth of interest and the birth of new techniques, due to their being non-invasive and with high time and space resolution.

The knowledge of elementary processes in atoms and molecules is necessary for optical diagnostics, especially in a strongly collisional regime like an ATP discharge. Paradoxically, it is exactly the applicative nature of PC that has pushed new investigations on fundamental molecular physics aspects relevant to optical spectroscopy. For example, we still discuss about the value of the cross section of non-resonant two-photon absorption [1]. What could be the its interest if this cross section value were not important for the measurement of O or N density by TALIF in, for example, plasma medicine devices? Who would care about excitation processes of the $OH(A^2\Sigma^+)$ state in a discharge if not to see how can the 3064 Å bands emission be used for gas temperature measurements [2]? Or of the temperature dependence of quenching and vibrational relaxation of $OH(A^2\Sigma^+, v=0,1)$, required for the CET-LIF technique [3]?

Studies on the identification of excitation processes, on collision rate constants, on the kinetics of excited states have then been made and require further efforts to employ correctly existing techniques, to avoid interpretation errors that still occur, and to design new diagnostics. Here this point of view is addressed, together with some examples that belong to our personal experience.

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I-01

Hybrid discharge plasma technologies for water decontamination

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Synthetic chemicals such as dyes, pharmaceuticals, herbicides, and pesticides, invented for industrial and agricultural applications and human healthcare, have been found in trace amounts in natural water bodies and even in drinking water. These contaminants pose a potential threat to the ecological safety and the health of human beings, and one of the direct source of these contaminants is effluent from wastewater plants into rivers. Electric discharge in contact with water in situ generates many kinds of reactive species (e.g. radical species of ·OH, $O_2^{\cdot-}$, ·O, ·H, HO_2·, NO_2·, and NO·, and molecular species of O_3, H_2O_2, and H_2), UV irradiation, and shockwaves, etc [1], and varieties of electric discharge technologies including dielectric barrier discharge (DBD), pulsed streamer discharge, glow discharge have presented their efficacy on destroying recalcitrant organic compounds in water. Although discharge plasma technologies for water decontamination have achieved many valuable results during the past 30 years, some technological difficulties and the high electricity consumption still exist for its successful application at industrial scales. In recent years, some hybrid processes of discharge plasma combined with adsorbents, catalysts, and oxidants have been developed to promote the degradation of pollutants, and higher and faster degradation of organic pollutants in water were realized. We will present some hybrid plasma processes studied in our group for removal of aqueous organic pollutants, for example, gas-liquid phase electric discharge combined with persulfate [2,3] and transition metal catalysts [4], and the water decontamination performance and potential mechanisms of these technologies will be presented.

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I-02

The interaction of atmospheric pressure plasmas with targets

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Being suitable for applications on sensitive substrates, for example polymers, but also organic matter including living tissue, non-thermal atmospheric pressure plasmas have undergone intense development in the recent years. However, their transient nature and small features make it challenging to perform diagnostics. Furthermore, their application area is in interaction with substrates of different properties, but the presence of a target almost always changes the properties of the plasma of this type. The focus of this work is the complex interplay between the effects of the target on the plasma and the plasma on the target.

This talk will address the interaction between the non-thermal atmospheric pressure plasmas and different types of substrates, with the emphasis on dielectrics and water.

I-03

Spectral line shape analysis as a tool for the diagnostics of atmospheric pressure discharges

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Optical emission spectroscopy (OES) is still the main tool for the diagnostics of a wide range of electrical gas discharges. The identification of the mechanisms that influence the atomic line shape enables insight into the values of various discharge parameters, such as gas temperature, electron density, and electric field strength [1]. For example, in low-pressure discharges, a proper resolving of the line broadening caused by the thermal motion of the emitters i.e. Doppler broadening results in a determination of the gas temperature. In the low-temperature gas discharges at atmospheric pressure, this type of broadening usually may be neglected, and pressure broadening mechanisms start to prevail. Resonant broadening and van der Waals broadening measurements lead to the determination of the gas temperature but also may serve for the estimation of the partial pressure of the perturbing gasses. The increased density of the charged particles induces elevated values of the microscopic electric field and causes Stark broadening of the emitted lines and the possibility of the estimation of the electron density and the electron temperature in plasma. If the emitters are subjected to the influence of the macroscopic electric field, as in the cathode region of the glow discharge or the head of the streamer, it will also cause the Stark effect, the line splitting and shifting, and in some cases the appearance of the forbidden lines that also shift in the electric field. Such lines may be used as a probe for the electric field strength determination [2].

We will show how the spectral line shape analysis is used for the diagnostics of various discharges at atmospheric pressure; including dielectric barrier discharges, free expanding plasma jets and plasma jets in contact with different targets, pulsed discharge with liquid electrode and discharge sliding over the liquid surface. The examples of the striking experiments with the practical advice on how to use each of the methods will be reviewed. Furthermore, we will mention how the obtained results improved the understanding of the physical processes both in the atmospheric pressure plasmas and in substances in contact with plasma.

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I-04

Low temperature plasma processes for constructing bioinstructive platforms for cell culture and tissue-integration

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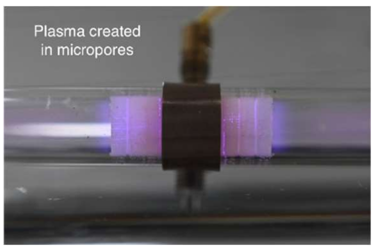
Materials used in biomedicine are selected according to bulk properties, such as mechanical, electrical and optical, required for particular in-vivo and in-vitro applications. However, their surfaces almost always provide suboptimum biological microenvironments and do not promote the desired biological responses. In addition, they are often formed into geometries that are not appropriate for traditional line-of-sight low pressure plasma treatment modalities.

This presentation will describe sustainable and readily scalable low temperature plasma surface modification processes, that enable resilient and easily tailorable biofunctionalization on all surfaces of complex, including microporous, fibrous or hollow-fibre-based, structures.

Typical time scales of cell culture and tissue integration necessitate covalent immobilisation to prevent interface instability due to desorption and exchange with molecules in the aqueous local environment. We will examine how these plasma treatments activate a range of materials and structures for spontaneous, reagent-free, covalent functionalisation with bioactive, cell-signalling molecules and hydrogels. Functional molecules that can be immobilised to create tailored, bioinstructive cell microenvironments include, but are not limited to, oligonucleotides, enzymes, peptides, aptamers, cytokines, antibodies, cell-adhesion extra-cellular matrix molecules and histological dyes. The covalent immobilisation occurs on contact via radicals or reactive groups embedded in the surface by energetic plasma species.

After a review of the fundamental science, processes to modify the internal surfaces of multi-well plates, porous scaffolds, microfluidic devices and other micro/nanostructures will be presented. Strategies for controlled immobilisation of biomolecular patterns and hydrogels onto the plasma activated surfaces will also be discussed. In particular, we will highlight how the plasma processes are adapted so that even difficult-to-reach surfaces in micropores and throughout 3D fibrous structures can be biofunctionalized and how the treatments impart dramatically enhanced functional stability to the immobilised biomolecules.



I-05

Plasma applications in analytical chemistry

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Analytical chemistry is a wide branch of chemistry focused on developing new analytical techniques and/or improving the analytical performance of established methods. One of the leading parts of analytical chemistry is electrochemistry employing electrode processes for the quantification of numerous chemicals. Among the many known electrodes, biosensors employing a biological element are becoming increasingly popular. Typically, the design procedure for a biosensor containing the enzyme laccase takes several hours [1-2], which significantly limits their widespread use. Therefore, one of the principal ongoing challenges in biotechnology is to minimise the time required to produce an effective biosensor with attractive analytical parameters. Therefore, non-equilibrium low-temperature plasma discharge was begun to be used in the construction of biosensors and the pioneering Soft Plasma Polymerisation (SPP) technique was developed. The need to introduce bio-based material into the discharge chamber required the construction of a discharge with a temperature not exceeding 40ºC operating at atmospheric pressure. Preliminary work by Herbert et al [3] demonstrated that the use of a corona discharge with a pin-to-plain configuration enables the polymerisation of organic monomers. Subsequently, investigations into the polymerisation of the enzyme laccase were initiated. The results presented in the paper [4] clearly demonstrated that the enzyme is efficiently polymerised in the corona discharge zone without significant loss of its biological activity. The combination of these two effects was a key point in the design of electrochemical laccase biosensors by the innovative SPP technique. In the paper [5], the optimisation of the plasma application process of the receptor layer and the analytical parameters of the obtained biosensors towards the determination of three dihydroxybenzene isomers (catechol, hydroquinone and resorcinol) were presented. These results indicated that the obtained laccase biosensors could not be used for the simultaneous determination of catechol and hydroquinone, which was solved by using a carbon interlayer [6].

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Oral communications

O-01

Investigating changes in physical properties of water as result of non-thermal plasma interaction (surface tension, viscosity and contact angles)

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The interaction between non-thermal plasma and water results in the formation of reactive plasma species such as RONS in water. Water thus formed is referred to as plasma activated water (PAW). The presence of reactive species allows the PAW to be used for wide range of applications in disinfection, medicine, agriculture, and food industries. A study [1] on the disinfection application of PAW found that it exhibits surfactant-like characteristics along with its sterilizing chemical effects. As a liquid with numerous applications, determining the physical properties of PAW, such as surface tension, viscosity and contact angles can help identify potential applications where PAW can be used for its physical properties or synergistic applications of its physical and chemical properties combined, such as in disinfection applications. In this study [2] physical properties, such as surface tension, viscosity and contact angles of PAW are investigated. PAW used in this study was generated using gliding arc plasma. The results of this study show that at room temperatures, plasma interaction lowers the surface tension and contact angle made by water; and the viscosity of PAW is lower than distilled water viscosity at low temperatures and viscosity is higher than distilled water viscosity at higher temperatures.

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O-02

Industrial dielectric barrier discharge plasma systems

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This paper presents one dielectric barrier discharge plasma technique (CPD) for industrial applications. It has been introduced to industries for gaseous and soil pollutants control. The cylinder type home-made ceramic dielectric has outer and inner diameters of 100mm and 80mm, respectively. Its active plasma length is about 800mm. The plasmas are produced on both side of the ceramic tube by applying pulse AC voltage. Their main characteristics of peak-peak voltage, pulse duration, repetition frequency and average power are around 50kV, 25μs, 5kHz and 50-100kW, respectively. Typical industrial applications are related to food, municipal sewage, incineration power plant, and chemical industries. This paper presents two examples.

As one example, for odor gas flow rate of up to 150000m^3/h and two 75KW CPDs are often used in series. The gas velocity inside the CPDs is around 12m/s. And then the direct plasma treatment time is less than 120ms. The odor pollutants are mainly NH_3, H_2S and CS_2. The odor intensity is reduced from around 3000-5000OU to be less than 500OU when the CPD energy density is around 1Wh/m^3.

For POPs polluted soil treatment, one 400kW system has been developed for treatment of 2t/h soil. Both lab and industrial tests have demonstrated for over 95% POPs decomposition, the energy cost is no morethan 200kWh/t (soil), which is much cheaper than traditional heating technique.

O-03

CO_2 conversion by nonthermal plasma: dielectric barrier discharge vs. transient spark

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As is well-known, carbon dioxide CO_2 is considered one of the most influential greenhouse gases with a significant detrimental effect on the Earth's climate [1]. Because of that the processes of CO_2 conversion and utilization have gained significant interest over the recent years. Among the potential technologies, a nonthermal plasma generated by atmospheric pressure electric discharges has shown very promising results [2]. Many authors reported their findings obtained by various discharges under different operating conditions (discharge energy density, composition of the gas mixture, gas flow rate, initial CO_2 concentration, etc.) [3]. Therefore, comparing the results and selecting the most efficient discharge is often difficult. For this reason, this study aimed to investigate the CO_2 conversion (removal) by two discharges of quite distinct properties (dielectric barrier discharge DBD and self-pulsing transient spark TS discharge) under the same operating conditions.

In this study, CO_2 conversion was investigated in a gas mixture of N_2 + CO_2 with an initial CO_2 concentration of 2.5 vol.%. Production of CO, as the only product of CO_2 conversion under the investigated conditions, was analyzed by FTIR absorption spectroscopy. The DBD reactor was of a cylindrical geometry and was either empty or packed with various catalytic pellets (TiO_2, $BaTiO_3$, MgO, ZrO_2, SiO_2, $BaTiO_3$+ZrO_2, $BaTiO_3$+SiO_2). The results showed that the presence of the catalyst in the DBD reactors significantly changed the characteristics of the generated discharge what was also clearly reflected in the results of CO_2 conversion. The TS discharge was generated in a pin-to-plane geometry with a gas flowing through a high voltage hollow electrode. The electrical characteristics of both discharge reactors, CO_2 conversion efficiency (in %) and energy efficiency (kWh/g) were examined and compared.

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O-04

Atmospheric pressure microwave plasmas for CO_2 conversion and CH_4 pyrolysis

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Conversion of CO_2 into the value-added chemical CO by plasmas is an alternative approach to the electrochemical and photochemical technologies. Recently, it was demonstrated that fast cooling of the 2.45 GHz microwave plasma effluent either by using a nozzle [1] or a water cooled channels [2] effectively reduces CO recombination to CO_2. This allows high CO_2 conversion and energy efficiencies to be obtained at atmospheric pressure, which are comparable to the previous highest values obtained at pressures in the range 100-200 mbar. Furthermore, a well controlled cooling of the plasma effluent allowed using larger 6 kW power supply to obtain CO outflows of up to 9 slm. Other aspects relevant for the implementation of the plasma conversion technology in an industrial environment such as: CO_2 inlet gas impurity, long term operation, and wall-plug efficiency have been tested, demonstrating good performance with up to 2 % of impurity (Ar, O_2, N_2) and steady performance over several plasma phases summing up to a total running time of 29.3 hours [3]. The measured wall-plug efficiency allowed to benchmark the plasma conversion technology with low- and high-temperature electrolysers in terms of performance, interfaces and economics.

The experience obtained investigating CO_2 plasmas is applied to CH_4 conversion to gaseous H_2 and solid carbon black. For that purpose, a custom made sampling system that includes both cyclone and filter separation was built. In order to obtain some basic plasma parameters, optical emission spectroscopy was used to determine the rotational temperature of the plasma inside the resonator by fitting the C_2 Swan band, yielding T_{rot} = 4200 K. Furthermore, an Echelle spectrometer with high spectral resolution was used to measure the profile of the H alpha line to determine the electron density in the plasma. Analysis of the products and the plasma properties allow us to assess the relevance of the microwave plasma for CH_4 conversion compared to other technologies.

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O-05

Plane parallel barrier discharge for carbon dioxide splitting: reactor optimization

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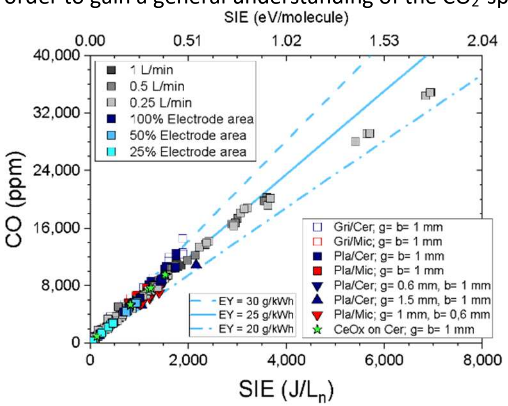
A planar volume dielectric barrier discharge (DBD) reactor in pure carbon dioxide (CO_2) for the formation of carbon monoxide (CO) is investigated. The influence of the type of the electrode (grid or plate), the barrier material (ceramic or mica), the barrier thickness (b), the discharge gap (g) [1], the presence of a CeO_x coating on the dielectric, the flow rate (and thus, residence time), the high voltage frequency and the electrode area (plasma volume) are varied systematically. The effect on CO formation and particularly its energy yield (EY) is evaluated.

The energy yield enables the comparison of the various reactors in the literature such as DBD-type reactors but also corona discharges, gliding arcs and microwave plasmas. In our asymmetric DBD reactors a maximal EY of 20 – 30 g_{CO}/kWh is found, independent on the reactor geometry, the flow rate, the high voltage parameters and or the barrier material (see fig. 1) or the mean reduced electric field strength. Specific energy inputs higher than 3 kJ/L_n yield to lower EY, but still higher than 20 g_{CO}/kWh.

A macroscopic model, developed for a symmetric volume DBD reactor in [2] is applied to our results in order to gain a general understanding of the CO_2-splitting in DBDs.



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O-06
Supported metal oxide materials for plasma-catalytic dry reforming of methane

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Plasma catalysis is gaining increasing interest for various gas conversion applications, such as CO_2 conversion into value-added chemicals and fuels, CH_4 activation into hydrogen, higher hydrocarbons or oxygenates and NH_3 synthesis [1]. Specifically, plasma is an electrical energy driven process, important for worldwide transition to renewable energy. Its highly energetic, collision-rich environment is able to activate relatively stable compounds at milder and more convenient conditions (ambient pressure and near-ambient temperature) than in classical thermal processes [2]. However, plasma catalysts currently have the drawback of not being selective and still requiring progress in energy efficiency. In addition, the interactions between plasma and catalyst are complex, as the chemical and physical properties of both can be modified by each other's presence [3]. The key challenge is then to design cost-effective, highly active, selective and stable catalysts tailored to the plasma environment. In this context, we evaluated the impact of several spherical γ-Al_2O_3 packing materials activated with different metal oxides on dry reforming of methane (DRM) to understand the influence of the metal oxide deposited on selectivity, conversion and plasma properties. All catalysts were synthesized using an incipient wetness impregnation procedure [4]. Commercial γ-Al_2O_3 microspheres with a diameter of 1.8 mm were used as support and different metal oxides (10 wt%) were selected as active elements. The reaction was performed in a packed bed DBD (dielectric barrier discharge) plasma reactor and the gas resulting from the reaction was analyzed downstream of the reactor with an online gas chromatograph. The CO_2, CH_4 and total conversion are clearly influenced by the presence of metal oxides on the γ-Al_2O_3 surface. Interesting results have been obtained regarding the selectivity of the different materials. Furthermore, the presence of the packing material acted as plasma modifier, changing the discharge properties.

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O-07

Kinetic study of CO_2 reforming of dimethyl ether in a nanosecond pulsed discharge

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The chemical kinetics of plasma-assisted CO_2 reforming of dimethyl ether (DME) is explored experimentally and numerically. Experiments are conducted in a flow reactor (DME/CO_2/Ar, 340K, 30 Torr) with a nanosecond pulsed dielectric barrier discharge (DBD). Synchrotron vacuum ultraviolet photoionization mass spectrometry (SVUV-PIMS) is employed to achieve the species measurement in this system. Nine ions are observed, including CH_3^+, O^+, Ar^{2+}, CO^+, CHO^+, Ar^+, CO_2^+, $CH_3OCH_2^+$, and $CH_3OCH_3^+$. Several intermediate species and products are identified based on the mass spectra and photoionization efficiency (PIE) spectra, such as methane (CH_4), water (H_2O), acetylene (C_2H_2), carbon dioxide (CO), ethylene (C_2H_4), formaldehyde (CH_2O), methanol (CH_3OH), ketene (CH_2CO), ethyl methyl ether ($C_2H_5OCH_3$), methyl formate (CH_3OCHO), and dimethoxymethane (DMM, $CH_3OCH_2OCH_3$). Species mole fraction profiles as a function of inlet CO_2 concentrations are obtained with the inlet CO_2 varying from 3% to 18% in the DME/CO_2/Ar mixture (n_{DME}=3%). The consumption of DME is promoted with the addition of CO_2, and the mole fractions of some products such as H_2O, CO, CH_3OH, and DMM increase firstly and then decrease. A kinetic mechanism incorporating plasma reactions and combustion reactions is developed for this system, and its prediction performance is tested against the experimental data. Rate of production (ROP) analysis is performed to reveal the key reaction pathways for the consumption of DME and CO_2 and the formation of products and intermediates. Specifically, DME is consumed through two channels, the H-atom abstractions with O/H/OH radicals and dissociations with plasma activated species such as electrons, Ar^+, and Ar^*. With the increase of the inlet CO_2 mole fractions, the former pathways are enhanced and the latter channels are weakened. Under the conditions investigated, more than 70% of the CO_2 consumption can be attributed to the electron/Ar^* collision dissociations forming CO and O. These channels are also responsible for more than 70% of the CO formation. The decrease of the electron density and electron temperature caused by the addition of CO_2 may account for the non-monotonic profile of the CO.

O-08

Sustainable NOx formation using high-frequency spark discharge plasma

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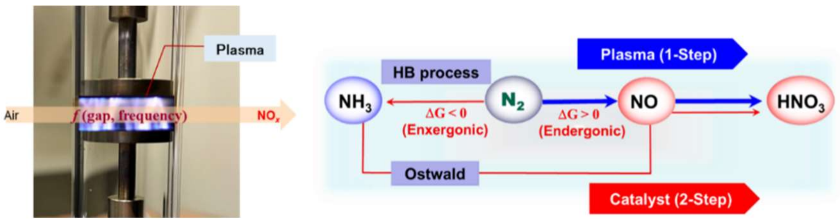
Artificial nitrogen fixation using plasma is one of the promising options for electricity-driven valuable compounds which is also referred to as power-to-X (X = H_2, NH_3, NO*x*, alcohols, etc) processes. In this work, we present one-step conversion of air into NOx by warm plasma, which is characterized by the higher vibrational and rotational temperatures than those of the nonthermal plasmas. High-frequency spark discharge showed much higher performance for NOx synthesis than conventional spark discharge operated at low frequencies. To get insight into the main factors for enhancing energy efficiency and understanding the underlying mechanism, the performance of the reactor was evaluated at different operating conditions. The results revealed that higher vibrational and rotational excitations at a higher frequency and a long electrode gap are critical factors in improving the efficiency of NO*x* production.



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O-09

The effect of different photocatalysts on nitrogen and oxygen chemistry in a dielectric barrier discharge plasma

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The use of photocatalytic materials in plasma systems has the potential to enhance the selectivity and yield of desired products. However, the surface interaction between the photocatalyst and plasma is a complex process that is not well understood. This work presents the diverse effect of two photocatalysts, zinc oxide, ZnO, and bismuth vanadate, $BiVO_4$ on nitrogen and oxygen plasma chemistry and the formation of end products. Both photocatalysts were produced as thin film coatings using reactive magnetron sputtering on the dielectric alumina plates, Al_2O_3, which were then incorporated within a dielectric barrier discharge (DBD) plasma reactor. The surface properties of the catalysts were examined using state-of-the-art surface analytical equipment including Scanning Electron Microscopy, X-ray Photoelectron Spectroscopy, Raman Spectroscopy and Atomic Force Microscopy to assess the topography, chemical composition and crystalline structure of the catalyst coating [1-3]. Ex-situ FTIR analyses of end products were carried out to qualify and quantify the generated end products. Oxygen concentration was varied between 0 and 100 %, while an applied voltage of around 6 kV and a total flow rate of 1 slm were used. Results show that ZnO coatings resulted in the formation of nitrogen dioxide, NO_2, and nitrous oxide N_2O. While with $BiVO_4$, ozone, O_3, was the main end product with small concentrations of N_2O. In the case of no coating, the main end products were O_3, Dinitrogen pentoxide, N_2O_5 and N_2O. These results prove the importance of the properties of the plasma facing surface on plasma chemistry and the formation of end products in the DBD. They also demonstrate the potential of tailoring plasma processes to suit the requirement of different applications.

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O-10

Nitrogenation of alkanes by dielectric-barrier post-discharges

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The state of physico-chemical knowledge regarding plasma treatment of polymer surfaces with nitrogen or N-containing gases is much less advanced than that of polymer treatment in oxygen. Surface modification of polypropylene (PP) by dielectric-barrier discharges (DBDs) in O_2 was modelled in detail already two decades ago. For DBD-based plasma nitrogenation of polymers, on the other hand, not even the first elementary steps of nitrogen incorporation are known so far, although the process has gained much interest in recent years for applications from adhesion enhancement over electroless metal deposition to biomedical purposes.

This contribution reports on nitrogenation of polyolefins and alkanes in post-discharges (PDs) of DBDs (DB-PDs) in N_2, with $N(^4S)$ atoms and metastable $N_2(A)$ as prevailing reactants. Solid or liquid alkanes are used as model compounds for crystalline and amorphous regions, of polyolefins, respectively. PD-exposed samples are analyzed by thin-layer chromatography (TLC), gas chromatography coupled with mass spectrometry (GC-MS), and FTIR spectroscopy. After chemical derivatization with strong IR absorbers, functional group densities down to 0.1 nm^{-2} can be quantified on ultrathin films. Cyclododecane (CDD) is of particular interest as a model alkane because it can form far fewer product isomers than e. g. n-$C_{12}H_{26}$, facilitating chemical analyses. Physical-vapor-deposited CDD films (40 nmol per cm^2 substrate area, d_{av} = 85 nm) are exposed to a stagnation-flow DB-PD (< 0.5 ppm O_2, T_{surf} = 195 K). According to TLC tests with dansyl chloride or fluorescamine reagents, the density of primary amines related to substrate area is below the detection limit (ca. 10 pmol/cm^2). After derivatization with 4-trifluoromethylbenzaldehyde (TFBA), CF_3-related IR bands (1324 cm^{-1}) in solution spectra of PD-exposed CDD show that ca. 10 nmol per cm^2 of substrate (60 nm^{-2}) TFBA-reactive groups form within 1 s of treatment, indicating a large actual surface area of the nanocrystalline CDD films. Expected signatures of aromatic N-alkyl aldimines in IR spectra ($\nu_{C=N}$, 1650 ± 10 cm^{-1}) are missing, raising the question how the aldehyde is bound to the PD-modified alkane.

The detection of cyclododecene and dodecene by GC-MS analysis of PD-exposed CDD agrees with the hypothesis that the excitation by energy transfer from $N_2(A)$ with subsequent loss of hydrogen or isomerization plays a role in the mechanism. The also detected nitriles and carboxylic acids may result from dehydrogenation of intermediate aldimines (-CH_2-CH=NH), forming -C≡N or keteneimines (>C=C=NH), the latter being hydrolyzed to ketenes (>C=C=O) and hydrated to acids (-CH_2-C(=O)OH) during product workup - so far in the presence of water.

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O-11

Plasma catalysis for nitrogen fixation to ammonia

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Ammonia is a carbon-free hydrogen carrier and a fundamental chemical compound widely used as an intermediate product for fertilizer synthesis. Thus, its global demand is projected to increase with the hydrogen economy and due to the world population growth. Plasma synthesis of ammonia is an emerging field for sustainable green NH_3 production, as it would allow the use of intermittent renewable sources [1]. The technology utilizes plasma processes to activate nitrogen molecules and promote reactions with hydrogen, potentially enhanced by catalytic materials. However, mechanisms of plasma catalysis may differ from those of thermal catalysis and are still not well understood [2] [3].

We have studied two types of discharges (dielectric barrier discharge and nanosecond pulsed discharge) to investigate their ammonia production performances by exploiting the catalytic effects of silver. Due to the difference in reactor geometries, we had to use two different catalyst supports. For the DBD, we utilized commercially available alumina spheres, whereas for the NPD, we designed and created cylindrical alumina monoliths [4].

This contribution will discuss the impact of supports and silver on ammonia production in the two discharges.

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O-12

Selective production of Reactive Oxygen and Nitrogen Species in Plasma-Activated Water

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Atmospheric air plasma produces a cocktail of reactive oxygen and nitrogen species (RONS) with multiple functions relevant to applications in biomedicine, agriculture, air and water cleaning, material treatment, food processing, etc. Achieving a precise control over a broad range of chemical species in plasma-activated water (PAW) and over physical effects occurring in plasma-liquid interactions is of utmost importance but remains a challenge.

We compare the formation of RONS in PAW, their concentrations, chemical reactions, and some of their antimicrobial and plant growth promoting effects, in various air plasma-water interaction systems: streamer corona and transient spark discharges without/with water electrospray [1-2], Fountain Dielectric Barrier Discharge reactor with different central electrode materials [3], surface DBD with liquid electrode, and glow discharge with liquid electrode.

Controlling the plasma-water interaction by varying the discharge type, the plasma power, the reactor volume, the electrode material and arrangement, the air flow conditions, and the water interface area (aerosol vs. bulk vs. thin film) enables us to selectively produce PAW with dominant ROS or RNS. E.g., low power streamer corona produces dominantly ozone, while higher power transient spark, DBDs, and glow discharge produce dominantly NOx leading to nitrites and nitrates in PAW. However, depending on the plasma-water interaction area, they also produce high amounts of H_2O_2 in PAW that reacts with nitrites leading to reactive peroxynitrites and hydroxyl radicals, which results in strong antimicrobial action [2-3].

We tested the oxidative vs. nitrative properties of the PAW by the degradation of methylene blue (MB) dye as a model water contaminant. The varying production of RONS leads to different pathways of the MB dye degradation: decomposition and bleaching is attributed to the H_2O_2 production, while its conversion to malachite green is due to nitration [6].

The fundamental understanding of plasma-water interaction systems can lead to optimized designs of plasma–water interaction systems for multiple applications.

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O-13

Plasma degradation of complex mixtures of antibiotics in water

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The main driver of this research is the continuous deterioration of water quality due to improper wastewater treatment. Water pollution together with the increasing scarcity of this invaluable resource and the rising demand are creating an alarming situation worldwide and have prompted the need for innovative and efficient water treatment solutions. Non-thermal plasma is one of the advanced oxidation techniques that proved effective at lab scale for the removal of a wide range of organic contaminants [1-3]. However, the large majority of these studies, is conducted with synthetic mono-component solutions prepared in high-purity water, thus being very different to real wastewater.

To be closer to real-life situations, this work investigated the plasma degradation of a mixture of four antibiotics belonging to different classes in tap water. Sulfamethoxazole, trimethoprim, clindamycin and ofloxacin were selected, as they are included on the most recent EU Watch List [4], the available information indicating that they may pose a significant risk to or via the aquatic environment, but monitoring data being yet insufficient to come to a conclusion on the actual risk posed.

A multi-wire corona discharge above liquid operated in pulsed mode was used, followed by an ozonation reactor that uses the effluent gas from the plasma [5]. The contaminants removal and process efficiency were determined for solution volumes of 500 mL containing 50 mg/L of each antibiotic. The plasma performance was compared with results obtained with mono- and bi-component solutions to detect changes in the degradation kinetics occurring in a complex water matrix.

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O-14

Consequences of direct electron impact onto liquid surfaces

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Atmospheric pressure plasmas in contact with liquids may activate the liquid through several avenues – solvation of plasma produced reactive neutral species, electrons and ions, and photoionization and photodissociation. When using negative discharges, the liquid can serve as either the direct or indirect anode. An anode-like sheath forms at the surface that can, even at atmospheric pressure, accelerate electrons onto the liquid surface with energies of a few to tens of eV. Electron collisions with surface-resident molecules can then result in dissociation and ionization. This direct impact process is thought to be one of the dominant mechanisms whereby surfactant molecules such as PFAS in water are remediated by plasmas. With positive discharges, analogous processes can occur at the cathode-serving liquid accelerating ions into the liquid. Although the penetration depth of electrons having tens eV of energy is only tens of nm, this is the realm of surfactant molecules. The contributions to activation of the liquid by these direct electron and ion impact processes, dominantly dissociation of surface resident molecules, are poorly known.

In this paper, results of a computational investigation of direct charged particle impact onto liquids will be discussed. The goal of the investigation is to quantify the contribution of direct electron impact dissociation and ionization to activation of water solutions through reactions with surface resident molecules. The investigation was performed using the *nonPDPSIM* modeling platform in which multiphase (gas and liquid) plasmas can be addressed. The test systems are pulsed positive and negative discharges sustained in atmospheric pressure humid rare gases to quantify contributions by direct electron impact to OH, H and O production in the surface layer. The dissociation of PFAS molecules in the water will be discussed as an example of reactions with a surfactant.

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O-15

Towards holistic wastewater treatment using activated carbon/zeolite coupled atmospheric plasma system

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Conventional wastewater treatment (WWT) systems are predominantly designed to target organic and ammonia removal, leaving micropollutants largely unaddressed [1]. Conversely, advanced oxidation processes (AOPs), while effective against most micropollutants, face limitations due to required optimized conditions like pH adjustment, hindering their use for holistic WWT. Moreover, the use of added chemicals in AOPs increases treatment costs and raises environmental concerns about potential residue in the treated effluent [2]. In this regard atmospheric pressure plasma-based systems can efficiently degrade organic pollutants without added chemicals or heat. The potential utilization of renewable energy further enhances plasma-based WWT's appeal as a standalone green technology [3].
In this study, a dual plasma discharge system was developed by integrating atmospheric plasma with activated carbon and zeolite to achieve simultaneous removal of organics, ammonia and targeted micropollutants along with disinfection. The first stage of the study will be presented which consists in a systematic investigation of the process efficiency on organics and ammonia and allowed to obtain their comprehensive removal from the treated wastewater. Furthermore, the study explores the regeneration of the adsorbents within the same system and compares the process energy efficiency with conventional wastewater treatment methods. The findings underscore the potential of the dual plasma discharge system as a standalone solution for holistic WWT.

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O-16

Application of gliding arc and dielectric barrier discharges on the treatment of poly- and perfluoroalkyl substances (PFAS)

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A variety of non-equilibrium plasma technologies have emerged as promising methods for the destruction of poly- and perfluoroalkyl substances (PFAS), a class of contaminants often referred to as “forever chemicals” because of their prevalence and persistence in the environment. This presentation will focus on our efforts in the research and development of using non-equilibrium reverse vortex flow gliding arc plasma discharges and dielectric barrier discharges to treat PFAS in contaminated environmental matrices (such as water, soil, sediments) and spent adsorbents (granular activated carbon and ion exchange resins). We will discuss our findings on the role of plasma generated chemical reactive species and thermal heat for different plasma gases and discharge regimes on the thermodynamics, kinetics, and mechanisms of degradation involved in the mineralization of PFAS compounds to CO_2 and HF/F^-. Lastly, we will describe our on-going efforts to scale-up these technologies and improve energy efficiency and reduce treatment costs for commercialization and full-scale deployment.

O-17

Purification of PFAS-contaminated groundwater by treatment with a RAdial discharge Plasma (RAP) reactor: the fate of degradation products

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Per- and polyfluoroalkyl Substances (PFAS) are synthetic aliphatic organic compounds resistant to natural degradation and thus currently spread throughout the aquatic environment and soil. Their presence in surface and groundwater requires the development of new purification methods capable of removing them efficiently. Advanced oxidation/reduction processes appear to be promising [1] and, among them, atmospheric pressure plasma is reported as the most energy efficient method in achieving high degrees of PFAS mineralization [2].

A RAdial discharge Plasma (RAP) reactor, patented by our research group for the degradation of PFAS in water [3], was investigated in this study and its efficacy in the purification of groundwater contaminated by PFAS was evaluated, with a particular attention on the formation and fate of degradation products. It is known from the literature that the plasma treatment of perfluorooctanoic acid (PFOA) and perfluorosulfonic acid (PFOS) leads to the production of shorter chain perfluoroalkyl carboxylic acids. It was, moreover, found that polyfluoroalkyl carboxylic acids, in which one or more fluorine atoms have been substituted by hydrogen atoms or hydroxyl groups (indicated below as 'substitution products'), are formed [4]. However, in most studies dealing with PFAS degradation, target analyses limited to quantify perfluorinated acids are performed, not allowing to ascertain the presence of substitution products and to identify other possible products. In this work, an analytical method based on solid phase extraction (SPE) and liquid chromatography coupled with mass spectrometry (LC/MS), that allows to concentrate and analyze PFAS formed as byproducts, whose presence is not generally monitored, will be presented and applied to the analysis of plasma treated groundwater contaminated by PFAS.

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O-18

Streamer discharge in air over a liquid surface: influence of permittivity and conductivity

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In air at atmospheric pressure, the application of an electric field higher than the breakdown field of air (30 kV/cm) can initiate the formation of a streamer discharge if the electron avalanches produce more than ~10^8charged species. At this stage, the space charge field of the streamer discharge may exceed the breakdown field and contains a high density of charged and reactive species. Due to its non-equilibrium thermodynamics, this discharge finds applications in various fields such as surface treatment or water purification. While the propagation of streamer in air is relatively well-understood, its interaction with solid or liquid surfaces complicates our understanding of the involved mechanisms. In this paper, we investigate the influence of liquid dielectric permittivity (ε_r) and electrical conductivity (σ) on the streamer dynamics generated by single-shot nanosecond high voltage. To achieve this goal, we utilize liquids with various ε_r(ranging from 32 to 80), while the solution conductivity is adjusted from 2 to 1000 µS/cm by adding KCl to water. The discharges are characterized electrically as well as optically by using 20-ns-integrated ICCD images (Fig. 1). Streamer propagation across a surface is primarily sustained by surface charging and charge accumulation. We find that decreasing ε_r accelerates surface charging, leading to more significant radial propagation, while an increase in σ results in the dissipation of surface charge due to presence of ions in the solution, leading to reduced radial propagation. Further details will be provided in the conference.

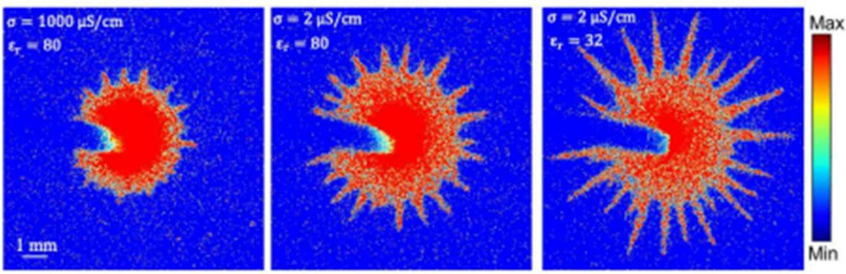

Figure 1. 20-ns-integrated ICCD images for discharge in air in contact with liquid at different ε_r and σ conditions.

O-19

Exploring the degradation intermediates of sulfamethoxazole during plasma treatment

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Pollutant removal from water using advanced oxidation processes, such as non-thermal plasma, has been intensely investigated in recent years [1]. Most of the time, the water treatment methods are evaluated based on the target compound's concentration or the total organic carbon [2]. A more accurate assessment of the treatment method could be made based on the formation and removal of different degradation intermediates during treatment [3].

In this study, the degradation of sulfamethoxazole and its intermediates was achieved using a combined plasma-ozonation system [4]. A pulsed corona discharge was generated above the pollutant solution using 110 ns pulses (full width at half maximum) of negative polarity with a voltage amplitude of 18 kV, at a frequency of 25 Hz. The identification of potential degradation intermediates of sulfamethoxazole was done using liquid chromatography coupled with tandem mass spectrometry (quadrupole-time of flight). The MS and MS^2 spectra were recorded in both positive and negative ionization mode using an electrospray ionization source and collision cell potentials in the range 0-25 V.

A series of 38 potential degradation products have been identified based on their MS^2 spectra recorded. Of those, most reached a maximum abundance at the beginning of the treatment (2, 5 or 10 min), and only nine were still detectable after 60 min of treatment. The degradation intermediates could be grouped in five main degradation paths. Two paths start with hydroxylation of either the benzene ring or the isoxazole ring, while a third is defined by the oxidation of the C9 methyl group to a carboxyl group. The last two paths consist of cleavage of the C–S bond or formation of an organosulfate intermediate. Overall, these results provide valuable insight into the plasma degradation of organic pollutants.

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O-20

DBD plasma treatment as a sustainable method for enhancing the wettability of jute fabrics

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Jute fibers are characterized by a complex layered structure with a hydrophobic surface outer layer consisting of a mixture of waxes and fats, which is responsible for jute low sorption properties. In this study, atmospheric pressure DBD operating in the air under different conditions (150 Hz or 300 Hz) was successfully used, instead of wet chemical processes, to modify jute fabrics' surface morphology and chemistry and consequently to tailor their wetting properties. The application of complementary techniques with different probe depths (ATR-FTIR and XPS) and different vertical resolutions (FE-SEM and AFM) allowed us to elucidate the exact range and location of surface changes caused by DBD-treatment. The obtained results suggest that DBD plasma treatments improved the wettability of jute fabrics, which is ascribed to changes in their surface chemistry (surface chemical composition, i.e. removal of surface impurities and non-cellulosic components, and incorporation of new functional groups) and morphology (increased roughness, new pores, and capillaries formed as a result of the etching and ablation of the fiber surface layers). Furthermore, the measurement of the electrokinetic and sorption properties could be used to follow changes in the surface chemistry of DBD-treated jute fabrics due to the post-plasma reactions. Special attention was paid to the aging effect investigated up to three weeks after plasma treatment. The obtained results revealed that both DBD treatments improved the sorption properties of jute fabrics, with the lower-frequency DBD treatment demonstrating greater efficiency. Plasma treated jute fabrics with improved wettability could be used as geo-prebiotic support for cyanobacteria growth in a novel solution for damaged land rehabilitation.

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O-21

Microdot-wise plasma polymer deposition from APGD-type DBDs

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This contribution reports about a phenomenon observed in plasma-enhanced chemical vapor deposition (PECVD) experiments using a "single-filament" dielectric barrier discharge (SF-DBD) in mixtures of argon with film precursors ("monomers", M) like hexamethyldisilane (HMDS) at atmospheric pressure. The experimental DBD setup consists of a vertical tungsten tip electrode glued to a borosilicate dielectric and a silicon wafer placed on a grounded aluminum plate, separated from the dielectric by a 2.5-mm gas gap. A transient atmospheric-pressure glow discharge (APGD) is formed in Penning mixtures (Ar + M) with molar fractions x_M between 10 and 250 ppm, where the region between a diffusive discharge channel and the silicon wafer consists of short (0.3 – 0.4 mm) rapidly moving filaments with diameters of 0.1 to 0.15 mm which can be observed with the naked eye. **Figure 1** shows a snap-shot of a discharge with admixtures of 25 ppm HMDS after 5 s deposition time from a video taken by a reflex camera. Interestingly, modelling results of the first breakdown event in Ar with admixture of 100 ppm HMDS, obtained by a time-dependent, spatially two-dimensional fluid-Poisson model, confirm the existence of a diffusive discharge region in front of the anode and the inception of a short filament starting from the diffusive region towards the silicon wafer (cathode). **Figure 2** shows the calculated electron density in cm^{-3} (in logarithmic scale) over the gap height z and radius r with r = 0 in the center of the tip electrode. Note that similar discharge dimensions in Figure 1 and 2 are observed. Resulting deposits are overall bell-shaped with diameters of ca. 1 mm. Higher-resolution topography, however, shows that deposition is microdot-wise resulting in typically 30,000 microdots/mm² with mean areas and volumes of 0.4 µm² and 0.05 µm³, respectively, see **Figure 3**. It will be further investigated if these film structures are related to the observed filaments, locally supplying film-forming ions.

Figure 1: Snap-shot of video after 5 s deposition time.

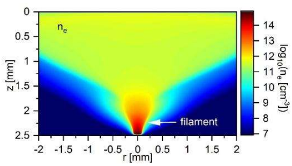

Figure 2: Modelled electron density distribution for 100 ppm HMDS in argon.

Figure 3: Microdot structure for a 60-s deposition.

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O-22

Fast low-temperature plasma-triggered self-propagation reduction-exfoliation process of graphene oxide materials

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Reduced graphene oxide (rGO) as a functionalized graphene-derived material possesses many great properties such as electrical conductivity and chemical inertness that are of great potential for many applications and new market opportunities. One of the greatest challenges in the commercialization of rGO is its production in bulk quantities and at low price. The most widely used methods are using hydrothermal and chemical reduction of graphene oxide into rGO. However, these methods are still technically complicated, time and energy consuming, and often environmentally problematic. We developed and studied a technically-simple, chemical-free, fast, and cost-effective „physical" alternative to the widely tested hydrothermal and chemical methods of GO reduction. We utilized the low temperature atmospheric plasma generated by Diffuse Coplanar Surface Barrier Discharge to trigger fast (~ 1-10 s) reduction & exfoliation of 3D porous GO aerogel-like materials [1] and also 2D GO paper-like films [2].

We studied the self-propagating reduction & exfoliation of graphene oxide into uniform rGO while the rGO structures retained their original shape without abrupt disintegration. We studied the plasma-triggering and self-propagating mechanism of the process depending on conditions of generated plasma (e.g. working gas, kHz and MHz power supply). We also compared the "cold" plasma-triggered reduction with "standard" thermal GO reduction triggered by heat, flame, or laser. Moreover, we investigated the properties of final product - the large area rGO structures that are interesting for the various practical industrial applications.

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O-23

Synthesis of gold/polymer thin films in Ar and Ar/NH_3 DBDs

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Atmospheric pressure plasma-enhanced chemical vapor deposition (AP-PECVD) is a low temperature process used for thin film deposition. One interesting aspect of working at atmospheric pressure is that liquids or colloidal solutions can be easily injected as an aerosol into the plasma. This can lead for instance to the growth of nanocomposite thin films, formed by nanoparticles (NPs) embedded into a matrix, through proper selection of the precursors [1]. One of the main benefits of this method is that NPs are not in any case directly manipulated, because both, the NPs and the matrix, are simultaneously synthesized in the plasma phase.

In this work, an aerosol of a solution of gold salt ($HAuCl_4 \bullet H_2O$, *i.e.* NPs precursor) dissolved in isopropanol (IPA, *i.e.* matrix precursor) is injected into a dual-frequency DBD. The evolution of the aerosol-droplet size is characterized prior to plasma entrance. According to [2], two plasma frequencies are applied: a high one (60kHz) for the matrix polymerization and the salt reduction, and a low one (800 Hz) controls the transport of NPs onto the substrate. In this research, the low frequency is continuously applied while the higher is modulated.

DBDs generated from pure argon (Ar) and argon mixed with 133 ppm of ammonia (NH_3) are compared. Electrical measurements and Optical Emission Spectroscopy (OES) were used to monitor the discharge. The morphology of the thin films was analyzed by Atomic Force Microscopy (AFM) and Scanning Electron Microscopy (SEM) and its chemical composition was provided by X-ray Photoelectron Spectroscopy (XPS) and Energy Dispersive X-ray Spectroscopy (EDX). Results suggest that despite similar discharge power densities in both cases (0.1 $W.cm^{-2}$), the NH_3 in the carrier gas seems to react with the gold salt before entering the plasma, as OES shows almost identical spectra between Ar/IPA and Ar/IPA/$HAuCl_4$/NH_3 plasmas. This points to the formation of NH_4AuCl_4, whose presence is confirmed by XPS and EDX measurements. This salt is harder to reduce as UV-Vis absorption spectra show little to no plasmonic response of the thin films unlike the ones made from pure Ar where peaks ranging from 540 to 750 nm depending on the process parameters are observed.

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O-24

Investigating changes in the chemical composition of liquid during polymer tube processing by SDBD

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The technique aimed to achieve uniform atmospheric pressure plasma treatment of inner and/or outer surfaces of polymeric tubes and other hollow bodies was developed by combining basic features of the Surface Dielectric Barrier Discharge (SDBD) and the plasmas in contact with liquids. Such configuration is favorable for the continual treatment of polymers. It could be used, for example, in processes such as activation and coating of biomedical devices, sterilization, cleaning, surface modification, etc.
This combined cold plasma discharge operating on the boundary of solid-liquid-gas holds great promise for industrial applications, yet a thorough investigation of its potential drawbacks is essential. Plasma, under specific conditions, can alter polymer materials by causing melting, etching, or even destruction. While in our previous studies, the damage of polymer tubes was not observed, dedicated experiments under well-defined conditions are necessary to investigate the changes in the chemical composition of the used liquids.
In this research, we conducted an examination and quantification of species present in the liquid phase produced during the processing of specific polymers by the SDBD. Using the HPLC technique, we quantified the amount of plasticizer leached from the inner surface of the tubes after plasma treatment. It was observed that while the amount of leached plasticizer from the polyvinyl chloride (PVC) tube increased with increasing treatment time and power, negligible amounts of by-products from polytetrafluoroethylene (PTFE) degradation were detected for longer treatment times. Also, we examined the inner surfaces of tubes both pre- and post-plasma treatment. Understanding the effects of material plasma processing is critical for ensuring the safety and effectiveness of plasma-based processes in industrial applications.

Acknowledgment: This research was supported by Marie S. Curie Action Postdoctoral Fellowship under Horizon Europe with grant agreement number 101066764.

O-25

Properties of Cr-doped Al_2O_3 as a dielectric barrier layer for atmospheric pressure discharges

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Dielectric barrier discharges are widely used in various branches of industry and research. The barrier layer materials have become the research subject in recent years due to motivation to enhance the discharge properties. It has been shown that even small changes in the barrier properties or composition can significantly affect discharge properties like ignition voltage and discharge homogeneity [1].
In this study, the authors present a complex investigation of the electrical and morphological properties of Cr-doped Alumina as a potential barrier for atmospheric pressure dielectric barrier discharges. Notably, two discharge types have been studied regarding the barriers' influence - coplanar dielectric barrier discharge (CDBD) in air and atmospheric pressure Townsend discharge (APTD) in nitrogen. The effect of the Cr-doping on the discharge has been characterized mainly via the ignition voltage measurement [2] and working domain (WD) measurement [3]. Additionally, the effect of doping on both bulk (permittivity) and surface properties, such as surface roughness and surface potential has been investigated.
The results show a significant difference in the suitability of APTD and CDBD regarding dopant concentration. The normalized ignition voltage measured in CDBD geometry showed an over 10 % decrease for 1 % of dopant, contrary to the expected dependence on permittivity. Compared to APTD working domain measurements, the 5 % doped alumina showed stable APTD over the most extensive frequency range up to 24 kHz. On the rest of the studied samples, WD was investigated over a range of 9-17 kHz frequencies, where two different APTD-like regimes were observed - a classical homogeneous discharge and a hybrid mode with a few localized filaments, with APTD current profiles most prevalent for 3 % and 5 % doped alumina.

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O-26

Influence of edge proximity on uniformity of atmospheric pressure plasma slit jet treatment of polypropylene

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Plasma treatment of polymer surfaces is a well-established application of atmospheric pressure discharges, such as plasma jets. Atmospheric pressure plasma jet is an overall term for all the atmospheric discharges whose plasma extends outside the electrode region into the ambient. This boundaryless configuration allows the treatment of 3D objects with complex non-planar surfaces, often cited as the plasma jet's most notable perk. However, studies of plasma jet interaction with non-planar complex surfaces are rare and focused only on analyzing discharge behavior and properties. This work investigated the influence of simple non-planar structure on the plasma treatment efficiency for the first time.

The 150 mm wide atmospheric pressure RF plasma slit jet (PSJ) ignited in three different gas feeds (Ar, Ar/O_2, and Ar/N_2) was used to treat block polypropylene samples. The edges of the non-planar samples enhanced the local electrical field, influencing the behavior of plasma filaments and, thus, the treatment. The main factor determining whether the treatment efficiency was different near the edges compared to the central surface area was the duration of the filament contact. It was affected by all studied parameters (gas feed, sample height, and treatment speed), with the gas feed being the most impactful choice. The Ar/O_2 PSJ filaments, whose sustainability was low due to electrons being lost in collisions with molecular gas and in the attachment processes, remained ensnared by the enhanced electric field of the edges the longest. Contrary to expectations, prolonged contact ensured the same treatment efficiency for all the surface areas. On the other hand, the Ar and Ar/N_2 filament behavior was only slightly impacted by the edge proximity, resulting in a shorter duration of filament contact. Therefore, at the higher movement speed of 250 mm/s, the treatment was less efficient close to the edges. In the Ar PSJ case, it was due to the high sustainability. During the Ar/N_2 PSJ treatment, only the diffuse part of filaments made mostly of neutral nitrogen species and low energy electrons touched the sample, hence the limited effect of the electric field.

O-27

Characterization of filamentary and diffuse DBD in CO_2 by optical emission spectroscopy and in-situ FTIR spectroscopy

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In the recent past years, the interest in CO_2 discharges increased in the frame of global warming induced by greenhouse gas emissions [1]. It motivated numerous studies dedicated to that topic, which significantly increase our knowledge in the field of CO_2 plasma chemistry but at the same time, numerous unknowns remain and new opened questions arise. To go deeper into these investigations, it is mandatory to have sets of experimental data in different and well-controlled conditions. For that purpose, extensive studies are done for example in low pressure DC discharges where the reduced electric field into the positive column is easy to assess [2]. It is much more difficult at atmospheric pressure since the discharges have generally non uniform structures. Nevertheless, the dominant processes being strongly dependent on the pressure, the need for reliable experimental data at atmospheric pressure remains. We recently showed that a diffuse dielectric barrier discharge (DBD) can be obtained in pure CO_2 [3]. In this regime called Atmospheric Pressure Townsend Discharge (APTD), the space charge is so low that the electric field across the gas gap is almost constant and can be easily determined by electrical measurements [4], making APTD a good tool for fundamental investigations of atmospheric pressure CO_2 plasma-chemistry. In this contribution, we present our last results concerning the characterization of CO_2 DBD by means of electrical and optical diagnostics. Systematic optical emission spectroscopy measurements were carried out for the diffuse and the filamentary regime in a plane-to-plane configuration and in a single filament regime in pin-to-pin configuration. In addition, in-situ Fourier transform infrared (FTIR) absorption spectroscopy measurements were performed in the filamentary and diffuse regimes for the plan-to-plan DBD. The obtained results will be presented and discussed in the present contribution.

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O-28

Correlation of ammonia synthesis rate with fluxes of atomic nitrogen and molecular nitrogen at vibrational excited states generated by an atmospheric-pressure plasma jet

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The contribution of atomic nitrogen is realistic in plasma-assisted catalytic synthesis of ammonia since it has high adsorption probabilities on solid surfaces. On the other hand, some papers in fundamental surface science report enhanced dissociative adsorption probability of vibrational excited molecular nitrogen, and recently, its contribution to catalytic synthesis of ammonia is discussed.
In this work, we compared the fluxes of atomic nitrogen and vibrational excited molecular nitrogen with the rate of plasma-assisted ammonia synthesis. We employed an atmospheric-pressure nitrogen plasma jet, and the spatial afterglow of the plasma jet and a hydrogen flow irradiated the surface of a ruthenium catalyst. The fluxes of atomic nitrogen and vibrational excited molecular nitrogen were measured by two-photon absorption laser-induced fluorescence spectroscopy and laser Raman scattering, respectively. As shown in Fig. 1, the synthesis rate of ammonia had positive correlation with the flux of vibrational excited molecular nitrogen, while the variation of the synthesis rate with the gas flow rate was opposite to the flux of atomic nitrogen. The experimental results indicate the contribution of vibrational excited molecular nitrogen to the synthesis of ammonia using the atmospheric-pressure plasma, where the flux of vibrational excited molecular nitrogen is more than four orders of magnitude higher than that of atomic nitrogen.

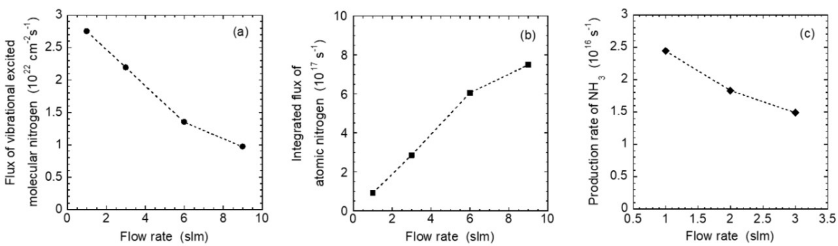

Figure 1 (a) Flux of vibrational excited molecular nitrogen, (b) flux of atomic nitrogen integrated in the cross section, and (c) the synthesis rate of ammonia as a function of the gas flow rate in an atmospheric-pressure plasma jet.

O-29

Spatio-temporal density distribution of all four Ar*(3p⁵4s) states in a pulsed-operated dielectric barrier discharge at elevated pressures

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Dielectric barrier discharges (DBDs) can be applied for plasma enhanced chemical vapour deposition processes such as the deposition of thin functional films at atmospheric pressure. In case of short gas-residence times realised by, for example, high working gas flows, ions play an important role in the deposition process [1]. A significant production channel for ionic species is provided by excited argon species, especially the metastable states, via Penning ionisation. The ability to determine the number density of all four $Ar^*(3p^5 4s)$ states as a function of the operation parameters, such as the gas flow or the characteristics of the applied high-voltage (HV) pulse, is required for the benchmarking of numerical models, see e.g. [2]. A planar, one-sided DBD consisting of a half-spherical, powered stainless steel electrode in contact with a planar dielectric (Al_2O_3, thickness: 0.6 mm, 0≈9) and a grounded, planar stainless steel electrode (gap distance: 3.0 mm) is investigated. Operating the DBD with HV square wave pulses leads to the ignition of an individual discharge event during both slopes of the HV pulse in this single-filament arrangement similar to [3]. Tunable diode laser absorption spectroscopy is utilised to measure the absolute number densities of the four lowest energetically excited states of argon. Spatio-temporal density measurements in combination with electrical characterisation and optical diagnostics allow to elucidate the role of argon excited species on the discharge dynamics of single-filament DBDs. First results are shown in Fig. 1.

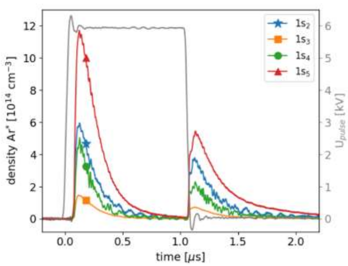

Fig. 1: Temporal evolution of the densities of all four Ar*(3p54s) states for a voltage pulse with an amplitude of 6 kV, a repetition frequency of 1 kHz, and a pulse width of 1 µs, measured in pure argon at atmospheric pressure.

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O-30

Temporally and spatially resolved radiation characteristics observed at the initial stage of nanosecond discharge in liquid water

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The experimental study [1] pointed out that a nanosecond discharge in liquid water is composed of nonluminous and luminous phases. The non-luminous dark phase, which creates bush-like structures made of thin hair-like filaments, occurs with a delay of a few nanoseconds after the onset of the HV pulse, and the propagation of every single filament is accompanied by GPa shock waves [2]. In contrast, the luminous phase has a simple tree-like morphology and is characterised by broadband continua extending from ultraviolet to near-infrared (NIR) wavelengths [3]. The onset is delayed by about 600 ps with respect to the onset of the dark phase. Recently, we obtained temporally and spatially resolved emission spectra of the nanosecond discharge together with images registered using a four-channel ICCD imager [4]. This enabled us to connect the morphology of the luminous discharge phase with the specific characteristics of the plasma-induced emission in the vis-NIR region [5]. We discovered that the initial diffuse morphology of the discharge is associated with broad-band emission spectra, whereas the subsequent filamentary morphology is linked to spectra featuring broadened hydrogen and oxygen atomic lines. In this work, we investigate the origin of the broad-band emission spectra captured in the first nanoseconds of the luminous phase by comparing them with model spectra obtained through three different methods: (i) electron–neutral bremsstrahlung generated by a bell-like energy distribution of the electrons, which is coherent with the concept of the electric field emission into electrostriction-induced nanovoids [6], (ii) considering the electron–neutral bremsstrahlung due to electron energy distribution derived from state-of-the-art cross-section sets for H_2O [7], (iii) considering high-pressure (GPa) broadening of hydrogen and oxygen atomic lines.

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O-31

Heavy hydrocarbon conversion in nanosecond pulsed discharges

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The surge in global demand driven by strict CO_2 emission regulations and energy market complexities has led to increased research into sustainable energy production and high-value hydrocarbon chemicals [1]. Non-LTE plasma shows promise for gas conversion due to its CO_2 neutrality, reasonable energy efficiency, and versatility with different hydrocarbons as feedstock [2]. However, achieving selectivity in plasma-induced chemistry, especially with aromatics like styrene, remains a significant challenge.

This study delves into styrene conversion using nanosecond pulsed plasma (Figure 1) to optimize the production of valuable C_xH_y compounds such as aromatics and alkanes. To tackle this challenging research, we used a mixture of styrene (0.5%) and Argon (99.5%), leveraging the well-understood chemistry of Ar in plasmas. Integration of experimental data with a global 0D modeling approach aims to elucidate complex plasma-chemical processes, especially focusing on combustion chemistry. This assumption was made based on the gas temperature, estimated at 2600K, measured by Rayleigh scattering and OES.

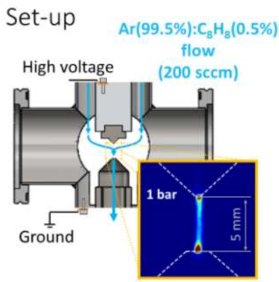

Figure 1: Schematic of the experimental set-up, including results from ICCD imaging of the plasma.

Our focus here is on the phenomenological characterization of the plasma. Experimental methodologies deployed in this investigation yield a comprehensive dataset crucial for understanding plasma-induced chemistry. Electrical characterization was conducted to ascertain pulse energy and duration. Gas temperature kinetics was gauged through two approaches: optical emission spectroscopy (OES) of C_2 Swan bands and Rayleigh scattering spectroscopy. Furthermore, electron density estimation was facilitated by observing the Stark broadening effect. These collected data have been integrated with 0D modeling, and preliminary findings are presented herein, including gas temperature and power density.

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O-32

Optical diagnostic of an Ar microwave plasma jet expanding in ambient air using hyperspectral imaging

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Optical diagnostics remain the most commonly applied technique for determining the properties of non-equilibrium plasmas. The strength of such a technique mainly stems from its non-disturbing nature and its simplicity to implement. If there is a drawback, it can be attributed to the lack of spatially resolved measurements as well as difficulties in coupling experimental data with models to determine fundamental plasma properties. Many researchers have made significant advances in this field to provide spatially resolved measurements. The applied techniques usually rely on point-by-point measurements or on coupling a camera with filters.

In this work, we introduce a novel optical tool for determining spatially resolved plasma parameters in atmospheric pressure plasmas. This is achieved by employing a hyperspectral imaging (HSI) technique based on a tunable Bragg-grating imager coupled with a scientific Complementary Metal–Oxide–Semiconductor camera. We outline the system's working principles and necessary post-processing steps to gather spectral and spatial mappings of optical emission. Herein, HSI is applied to an Ar microwave plasma jet expanding into ambient air, and the spatial resolution of the acquired data is 13.9 µm. The data are post-processed by performing Abel transform to determine 2D radially-resolved spatial mappings. The data allow us to map fundamental plasma properties, including excitation temperature from line emission intensities emanating from upper Ar energy levels (>5p), metastable number density (Ar 4s states) from Ar 4p-to-4s line emission intensities in the optically-thick media, as well as neutral gas temperature from the line broadening of Ar 4p-to-4s transitions. With the last cartography in hand, coupled with the collisional Radiative Model developed by A. Durocher-Jean [1], the electronic temperature cartography is also calculated. Over the range of experimental conditions investigated, electron temperatures are between 1.2 and 1.5 eV, with a slight increase close to the outer limits of the jets. The spatially resolved data will be further processed to visualize gradients of the plasma parameters. We are convinced that such data will improve our understanding not only of plasma jet physics but also of plasma jet-surface interactions, thereby aiding in the further development and optimization of plasma applications.

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O-33

Utilization of the Stark effect in micro-scaled DBDs for the determination of fundamental plasma parameters

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Micro-scaled dielectric barrier discharges (DBDs) at atmospheric pressure are emerging as a promising technology for applications such as converting environmentally harmful gases like CO_2 or volatile organic compounds. To further increase the efficiency of these conversion processes, the deposition of a catalyst onto the dielectric surface is reasonable. However, the interaction between the catalyst and the plasma discharge is poorly understood. In addition to the important production of reactive species within the discharge and their transport to the catalysts, the electric field perpendicular to the surface and the charging of the catalyst can significantly influence the synergistic effects [1]. Therefore, a holistic view of the discharge, including the directional electric field strength and the electron density, is of utmost importance. To determine these parameters, we use an optical emission spectroscopy (OES) approach where we analyze spectral lines that were strongly influenced by the Stark effect.
Here, we investigate the micro-cavity plasma array (MCPA), which is easily scalable for industrial applications while having good diagnostic accessibility to study the synergistic effect between plasma and catalyst [2]. The MCPA comprises numerous cavities, each measuring hundreds of micrometers, in which a discharge can be ignited. For the directional electric field components, we measured phase-resolved polarized spectra of the shifting and splitting of the allowed 492.19 nm ($^1D \rightarrow {}^1P^0$) and forbidden 492.06 nm ($^1F^0 \rightarrow {}^1P^0$) helium line pair. This diagnostic approach requires a non-radially symmetric geometry, which leads to an adapted reactor design of the MCPA that allows the side-on observation of the discharge.
The discharge operates in pure helium at atmospheric pressure, with a bipolar triangular voltage of 600 V amplitude and 15 kHz frequency. The results show significant differences in the electric field components. The electric field component perpendicular to the dielectric surface is about 22 kV cm^{-1}, while the component parallel to the surface is about 5 kV cm^{-1} larger during the decreasing potential phase of the applied voltage [3]. Furthermore, the temporal evolution of the field components demonstrates the shielding effect that arises from the ongoing charging of the dielectric surface.

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O-34

Study of ion formation of alkanes in atmospheric pressure by ion mobility-mass spectrometry (IM-MS)

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In this work, we are focusing on the study of the plasma-chemical processes of alkanes (pentane, hexane, heptane, octane) in atmospheric pressure point to plane corona discharge. The detection of the neutral products of investigated samples will be carried out by homemade ion mobility spectrometry (IMS) and mass spectrometry (MS) using the Atmospheric Pressure Chemical Ionization (APCI) method. In the corona discharge reactor, the processes of fragmentation of alkanes and synthesis of new hydrocarbons have been studied. Due to low acidity/basicity and the lack of ion acceptor functional groups in their structures, the analysis of saturated alkanes remains a challenge using mass spectrometry [1, 2]. The experimental setup for ionization and transforming alkanes to IMS consists of the external corona discharge, carrier gas, syringe pump for injecting sample, and IMS as a detector. Alkanes were ionized by using an external corona discharge system and the neutral products were transferred to IMS to be ionized and detected. The external corona discharge was operated in three different gases (N_2. O_2 and Air) at discharge currents 3µA and 10 µA. In all cases, the external corona discharge had positive polarity. The investigated samples had a significant response in IMS after treatment by external corona discharge.

Acknowledgment
The present studies were supported by the Slovak Grant Agency for Science VEGA Nr. 1/0489/21, Slovak Research and Development Agency under project Nr. APVV-19-0386 and Nr. APVV-22-0133.

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O-35

Plasma-driven chemistry in liquid microdroplets as a tool for the perovskite nanoparticles synthesis

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Physico-chemical processes occurring in liquids in result of interaction with plasmas have been recently intensively studied and applied in nanofabrication allowing to go beyond traditional equilibrium processes and expanding a variety of nanomaterials produced. Non-equilibrium plasma-induced reactions involve species having a high activity and resulting in the processes mostly occurring near the plasma-liquid interface. Hence, further increase of nanoparticles (NPs) production efficiency can be achieved upon increase of the liquid surface interacting with plasma that can be reached in microdroplets (Figure 1a). Such an approach has already shown to be efficient for the production of Au NPs [1]. Here, we demonstrate the applicability of the developed method for the formation of perovskite oxide nanoparticles. The developed approach uses non-equilibrium chemistry induced at the surface of microdroplets containing precursors solution as a result of interaction with RF plasma (110 W, 13.56 MHz). Elucidation of the critical experimental parameters, such as liquid and shroud gas flow rates, plasma power and precursor composition, allowed finding the conditions for the production of crystalline perovskite $LaNiO_3$ quantum dots with size in the range of 1-10 nm composed of rhombohedral phase proved by STEM, HRTEM and EDX measurements (Figure 1 b,c). Thus, the developed technique is offering a novel simple, controllable and versatile strategy for the production of nanomaterials of multi-element composition. The work was supported by the UK Royal Society Newton International Fellowship under Grant NIF\R1\221880.

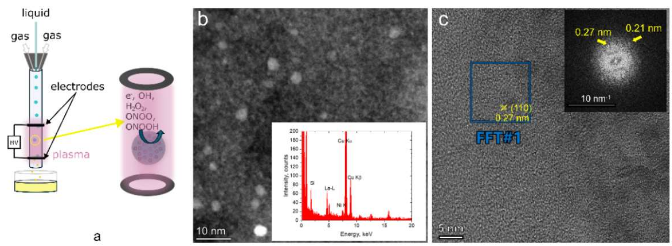

Figure 1. Synthesis of $LaNiO_3$ NPs in plasma-processed liquid droplets: a – scheme of the experimental setup, b – STEM and c – high resolution TEM image of the NPs produced, the insets show the EDX spectrum of the NPs and results of FFT processing of the selected NP.

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O-36

Inferring viral aerosol protein damage from non-thermal plasma exposure using a Wide-Band Integrated Bioaerosol Spectrometer (WIBS)

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The global COVID-19 pandemic sparked dramatic expansion in research related to bioaerosols, and the transmission and mitigation of airborne infectious disease. Non-thermal plasma (NTP) is one such technology, having been shown to neutralize airborne pathogens [1-4] in flowing air streams more compactly and with less hydraulic resistance than UV irradiation or HEPA filtration. In our previous studies using an NTP reactor continuously supplied with a flow of bacteriophage-laden air [5], good agreement exists between aerosol number concentrations and number concentrations of the bacteriophage genome, suggesting that the mechanism of virus inactivation was not the destruction of the phage genome. One hypothesis for the mechanism of inactivation is that the momentary exposure of viral aerosols to an NTP causes damage to the outer capsid shell, including damage to the spike protein which initiates host cell attachment and entry. Since certain proteins and amino acids fluoresce when probed with an appropriate wavelength of light, the present study uses a Wide-Band Integrated Bioaerosol Spectrometer (WIBS) to detect changes in virus fluorescence resulting from NTP exposure, a possible indication of capsid protein damage.

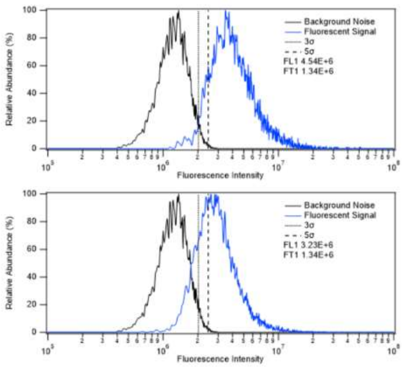

Figure 1. Fluorescence intensity distributions of bacteriophage MS2 aerosols before (top) and after (bottom) plasma exposure.

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O-37

Hydrogels as models to quantify the distribution and penetration of plasma-generated reactive species on tissues

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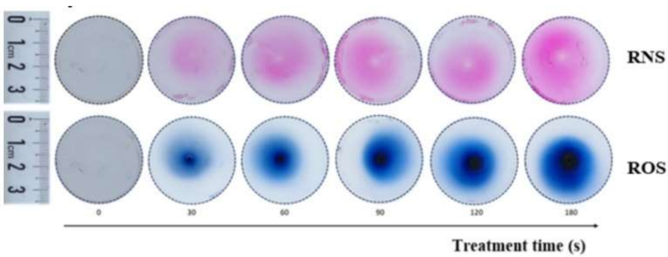
Hydrogels are used for various biomedical applications, such as tissue modelling, drug delivery, tissue regeneration, and medical dressings. They have recently been introduced in plasma medicine with two main purposes: 1) as models to study the interaction of plasma-generated reactive species (RS) with soft tissues, and 2) as vehicles for local RS delivery [1].

The objective of this investigation is to evaluate qualitatively and quantitatively the distribution and penetration of plasma-generated RS, in solid hydrogels based on gelatin and agarose. The penetration and distribution of RS in the hydrogels have been studied using colorimetric probes. Furthermore, a novel protocol has been developed to quantify the concentration of RS in hydrogels by means of calibration curves and image analysis. The results demonstrate a distinct time dependence of the amount of RS that is able to diffuse and penetrate in and through the hydrogel (see figure) and suggest some important differences between agarose and gelatin-based hydrogels. These differences, based on the physic-chemical properties of the hydrogels (concentration, structure, molecular weight, etc…) will be analyzed and discussed.



Acknowledgements. Authors acknowledge UPC (Grant no. R-02396, ALECTORS-2023), the Spanish ministry (project MCIN/AEI/10.13039/ 501100011033) and NextGenerationEU/PRTR and AEI (PID2022-141120OB-I00). Authors acknowledge COST Action CA20114 PlasTHER and belong to the SGR2021 01368.

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O-38

Improvement of seeds germination parameters by plasma treatment and investigation of the reached characteristics during their long-term storage

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As has already been shown, the application of non-thermal plasma to the various types of seed can improve the germination and vigour of the seedlings [1-3]. Depending on the type of seed, its size, shape and location of the embryo under the seed coat, different parameters of plasma treatment (plasma source, carrier gas, exposure time, etc.) are suitable to improve the germination parameters.

Usually, germination of the studied seeds is initiated immediately after plasma treatment, so that there is little information on the durability of the plasma-induced changes if long-term storage of the seeds prior to sowing is considered. The ageing effect is well known for plasma-treated substrates of different composition (glass, metal, plastic). Depending on the conditions of the plasma treatment and the nature of the substrate, the plasma-induced changes are not permanent, and the surface properties may return to their initial state over time. However, the ageing effect of plasma-treated seeds in relation to germination parameters has not yet been investigated.

In present study, we monitored the physicochemical and physiological changes of different seed types for five weeks after plasma treatment. An efficient plasma source with high power density plasma, the so-called diffuse coplanar surface barrier discharge (DCSBD), was used for our experiments. The physicochemical surface properties such as wettability, morphology and chemical changes of the plasma-treated seeds were determined by water contact angle (WCA) measurements, scanning electron microscopy (SEM), X-ray photoelectron spectroscopy (XPS) and Fourier-transformed infrared spectroscopy (FTIR). The physiological characteristics of the plasma-treated seeds, such as germination and growth parameters (length of roots and shoots, their fresh and dry weights, germination vitality indices) were carried out on the seeds every week after plasma treatment over a period of five weeks.

Surprisingly, the achieved WCA values on the seed surface remain stable for five weeks, as well as the observed chemical changes monitored by XPS. The ageing effect of plasma-treated seeds is therefore negligible, which is confirmed by the germination parameters obtained, since the physiological characteristics induced by the plasma treatment are also maintained over a period of five weeks.

This work was supported by the Slovak Research and Development Agency under the Contract no. APVV-21-0147.

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O-39

Plasma activated water applications in agriculture

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Non-thermal plasma technologies are getting more due to the effects on plants, microorganism and water. By treatment of water with non-thermal plasma, he reactive oxygen and nitrogen species (RONS) penetrate the water surface and created stable molecules of hydrogen peroxide, nitrite and nitrate. Due to the content of these RONS, this plasma treated water, often referred to as plasma activated water (PAW). Nitrogen species in water help with the growth of plants while hydrogen peroxide and lower pH give the water antibacterial properties [1].

Due to PAWs properties, it has been suggested that it may be utilized as a new type of liquid fertilizer. In this work, PAW's effect on plants was studied in various stages of their growth. Seed germination and early growth was studied on seeds of durum wheat *Triticum durum* and maize *Zea mays*. Plants of radish *Raphanus sativus* were treated with PAW for a month during a pot experiment. The effects of PAW on radish were evaluated by the weight of fresh and dry matter, content of chlorophyll and chlorophyll fluorescence, as well as determination of nutrients such as N, O and C by the elemental analysis.

PAW can also decrease the negative effect of heavy metals on the plant growth. A special type of test was conducted by growing of technical hemp *Cannabis sativa* in hydroponic medium which consisted of PAW with various concentrations of heavy metals (Cd or Pb). The PAW effect on *C. sativa* during the heavy metal contamination was assessed by toxicological endpoints (length of the root, the stem, and the whole plant). The spatial distribution of Cd, Pb and various nutrients was determined by the Laser-Induced Breakdown Spectroscopy (LIBS) [2].

Acknowledgments: This work was carried out within the frame of COST Action CA19110. LČ and DH gratefully acknowledge the support of grant No. FCH/FSI-J-23-8250 (Brno University of Technology) and the grant No. 23-13617L (Czech Science Foundation).

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O-40

Review of power supply systems of plasma reactors with DBD, GAD and APPJ

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A review of the power supply systems (PSS) of the atmospheric pressure cold plasma (APCP) reactors with dielectric barrier discharge (DBDs), atmospheric pressure plasma jets (APPJs) and gliding arc discharges (GADs) has been presented. This choice is due to the following reasons: the reactor's design is well developed and relatively simple, the potential area of application is large, ranging from energy, environmental engineering, biotechnology to medicine, and theses reactors can be powered from similar sources using non-linear transformer magnetic circuits and power electronics systems [1,2,3]. Attention has been paid to non-linear phenomena occurring in the power systems of plasma reactors, such as the generation of higher voltage harmonics, resonance and ferroresonance, impulse energy, switching overvoltages, which can improve the operating characteristics of non-thermal plasma reactors , facilitate the ignition of discharges, adjust the power supply parameters to the working gas and requirements of the plasma-chemical process [4,5,6].

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O-41

Effect of residual surface charge on generating the atmospheric pressure Townsend discharge in air

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We succeeded in generating an Atmospheric Pressure Townsend Discharge (APTD) even in air by using a specific alumina barrier [1]. In this work, we investigated the effect of residual surface charge on generating APTD in air.

Discharge device consists of a hemispherical rod electrode and an alumina embedded plane electrode (thickness of the ceramic part: 1 mm)[2]. The radius of the hemisphere and the gap length were 5 mm and 3 mm, respectively. A sinusoidal voltage of 11.8 kVp with 50 Hz was applied to the hemispherical rod electrode. Five cycles of sinusoidal voltage were applied to accumulate charges on the barrier surface. After the voltage application ceased, a half-cycle of positive sinusoidal voltage was applied to the hemispherical rod electrode.

Fig. 1 and Fig. 2 show applied voltage and current waveforms after various off-time, and the relation between off-time and probability of discharge mode. When off-time was set to 1 s or less, APTD was generated in the gap. On the other hand, when off-time was extended from 1 s to 10 s, APTD and streamer discharge appeared sequentially in the gap. When off-time was set to 100 s, APTD sometimes did not occur. These results suggested that not only charge accumulation on the barrier, but also the existence of a residual channel in the gap is important for generating APTD in air.

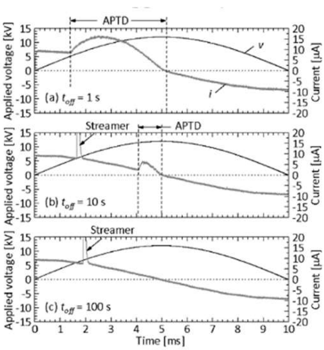

Fig. 1 Voltage and current waveforms after off-time.

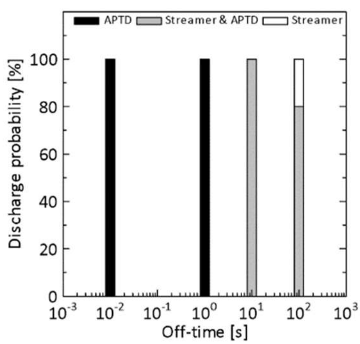

Fig. 2 Relation between off-time and discharge modes.

This work was supported by JSPS KAKENHI Grant Number JP23K03824.

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O-42

Can electrical parameters in nitrogen discharges at atmospheric pressure be used to study physico-chemical modifications in real time?

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Advanced functionalization of polymers has received a lot of interest because their potential to control surfaces and interfaces for different industrial applications. Today, several methods exist including wet-chemical treatments dry treatments. However, wet-chemistry usually employs hazardous reagents (*e.g*., metallic sodium-ammonia for PTFE modifications) and/or produce harmful residual products. Moreover, these approaches lead to the loss of optical and mechanical properties due to strong diffusions of chemicals in the materials. In the last decade, atmospheric pressure plasma systems have been widely used to change the surface properties. The litterature report that enhancement of adhesion, wettability, and biocompatibility is possible with plasma without affecting the bulk. For cost-effective industrial processes, nitrogen or air are the most common carrier gases. However, physical regime of the discharge strongly changes, depending on the gas, the geometry or the electrical signals used which lead to different surface modifications depending on the type of plasma used. In this context, the use of in-situ diagnostics to control the parameters remains essential to ensure the reproducibility of the final products. Hence, gaining insight into how the plasma and the substrate influence each other is crucial. In this work, we report the recent results obtained to modify fluorinated films with nitrogen in a dielectric barrier discharge with a roll-to-roll configuration. Samples were characterized by Atomic Force Microscopy, X-ray Photoelectron Spectroscopy, T-peel test and wettability. Specific electrical measurements were also performed to correlate the modifications of the surface proprieties over time with an in-situ analysis. Experiments revealed that the discharge rise the value of the initial capacitance and preliminary data suggest that the values can be correlated to the adhesion properties of the modified surfaces.

O-43

Filament interaction in pulsed dielectric barrier discharges

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The formation and interaction of individual filaments in dielectric barrier discharges (DBDs) are essential for the efficiency and efficacy of DBD reactors. In most DBD arrangements, multiple filaments are formed, since the transferred energy and therefore the power per filament is limited and can be controlled, e.g. by the pulse width of the applied high-voltage (HV) pulse [1,2]. In this study, the impact of O_2 concentration, HV pulse parameters, and gap distance on the number of filaments per period and their ignition pattern is studied in a spatially 1D multi-filament arrangement. The cylindrical, alumina-covered electrodes were arranged to enable a lateral gap length of about 10 mm while the gap distance was set to 0.5 and 1.0 mm, respectively. The working gas was a binary mixture ranging from 0.1 to 20 vol% O_2 in N_2 at atmospheric pressure. The DBDs were studied by iCCD camera imaging determining the filament number and the discharge development by a streak camera to obtain the filament positions during different phases of one HV period. Simultaneously, electrical measurements using fast probes were performed. The results clearly show the different effects of the performed parameter variations, particularly regarding the spatial stability and number of filaments, see Fig. 1 for the impact of the O_2 concentration. – Funded by the DFG (project number 466331904).

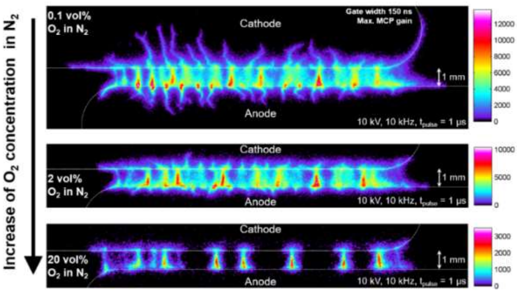

Fig. 1
Discharge emission struc- ture as a function of the O2 concentration at the rising slope of a 10 kV HV pulse with 1 µs pulse width for a repetition frequency of 10 kHz.

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O-44

Agglomeration effect of bipolar-charged airborne particles induced by a dielectric barrier discharge (DBD)

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Electrostatic precipitators (ESPs) are known for their high total mass filtration efficiency. However, their efficiency in filtering submicron particles is relatively low. This inefficiency arises from the inability of these minute particles to accumulate a sufficient electric charge that would enable their capture in the precipitator's electric field. A potential solution to this challenge is the agglomeration of smaller particles into larger ones using electrostatic forces. This paper presents our research findings on the agglomeration effect of bipolar-charged airborne particles, which is induced by a dielectric barrier discharge (DBD). We examined the impact of various agglomerator parameters, including its geometry, the discharge voltage, and frequency, on the size and fractional distribution of the resulting agglomerates. Additionally, we studied the effects of air flow velocity and agglomeration time. Our findings were then compared with those obtained using a traditional corona-type agglomerator.

O-45

Micro-second pulse and RF coupling in an atmospheric pressure plasma jet

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Controlling the interaction between plasma and surfaces in atmospheric pressure plasma jets is crucial for various applications, ranging from liquid and tissue treatments to the deposition of functional coatings. Key factors include the reactivity of the environment determined by electron density and temperature, induced electric fields, current, and localized heating. To address these challenges, we propose combining a microsecond pulsed power supply with an RF (27.12 MHz) generator within the same plasma jet. We will investigate the coupling of these two excitation frequencies through electrical and time-resolved optical emission analyses. Additionally, the plasma will be characterized using optical emission spectroscopy to compare different configurations. The discussion will be supported by comparing the results with a 2D fluid model in the time domain.

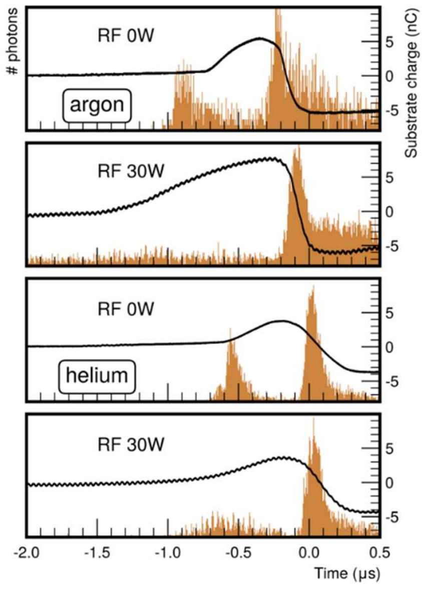

Figure 1. *Photons emitted within the first 1 mm above a glass sample and charge collected with different gases with and without the RF coupling.*

Experimental observations have highlighted the RF nature of the coupled plasma, where the microsecond pulse enables gradual control of ion flux to the substrate. Consequently, the plasma does not self-propagate, but its interaction is governed by capacitive coupling, offering improved homogeneity and high plasma density simultaneously. These novel interaction features hold promise for advancing the treatment of liquids [1] and biological tissues.

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O-46

Coplanar dielectric barrier discharge at MHz frequencies in Argon and Argon/Nitrogen mixture

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Dielectric barrier discharges (DBD) play an important role in industry as well as in research. DBDs are most often supplied by high voltage (HV) resonant transformer commonly operating at frequencies up to several hundreds of kHz. Recent developments in electronic and new ferrite cores allowed us to design and build new HV resonant transformers based on planar transformer technology [1] with frequencies up to 3.5 MHz with amplitudes up to 8 $kV_{p\text{-}p}$.

Besides standard volume DBD, studied e.g. in [2], we successfully ignited coplanar dielectric barrier discharge (CDBD) in pure Ar and Ar/N_2 mixture up to flow-rates 1:1. Visually "filaments", shown on Fig. 1, are spatially stable, up to 1 mm high and with high light intensity and on electrodes, there is "diffuse" part that covers the space above electrodes. Spectrum reveals increasing rotational temperature of N_2 from 600 K up to 850 K with increasing input voltage (power), while vibrational temperatures remain almost constant at 2700 K. This shows the potential for various applications, e.g. gas conversion, atomizers, etc.

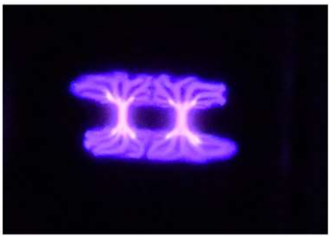

Fig. 1. The photo of two filaments on CDBD electrode in Ar/N_2 mixture at flow Ar: 0,31 l/min and N_2: 0,1 l/min at frequency 3.36 MHz.

This research has been supported by the Czech Science Foundation under Contract 23-05974K and by the Project LM2023039 funded by the Ministry of Education, Youth and Sports of the Czech Republic.

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O-47

Investigation of the diffuse nanosecond discharge characteristics under double pulse experiments in different N_2/O_2 mixtures

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Diffuse discharges generated in air by extreme high overvoltage do not tend to branch even under atmospheric pressure. In this work, we try to investigate the discharge characteristics in 'double pulse' experiments to find out the morphological differences between two consecutive discharges, and the effect of the inter-pulse delay. The classic discharge morphology in different N_2/O_2 mixtures under atmospheric pressure is shown in Figure 1, showing that the second pulse discharge in low oxygen concentration mixtures may become filamentary. Besides, through repeated experiments, it is found that the branching probability is related to the inter-pulse time delay (Δt): in the 2% and 0.2% mixtures, the branching probability gradually decreases with Δt and after a certain Δt, the second discharge becomes diffuse again. We also try to explain this branching phenomenon through fluid modelling and plasma diagnostic methods.

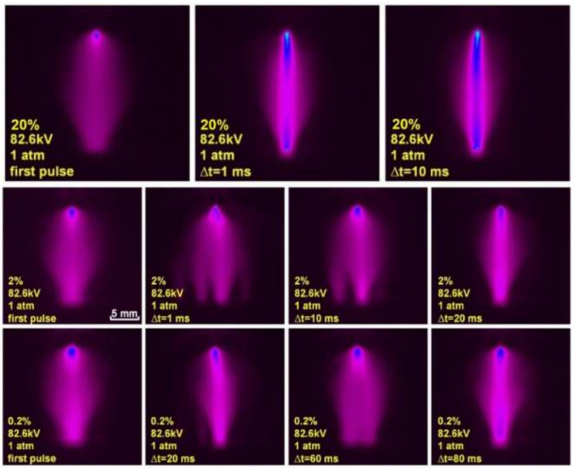

Figure 1. The discharge morphology in 20%, 2%, and 0.2% oxygen concentration N_2/O_2 mixtures. The nanosecond pulse voltage amplitude is 82.6 kV and the pressure is 1 atm. Δt is the pulse interval between two discharges.

O-48

Diffuse DBD memory effect in air: surface and volume mechanisms

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Generally, two discharge regimes are observed in Dielectric Barrier Discharge at atmospheric pressure: filamentary and diffuse [1]. For some applications, such as plasma coating, the diffuse discharge is more appropriate [2] thanks to its homogeneous injection of the energy, allowing a more uniform dissociation of the precursor and a more uniform and dense coating. However, to obtain this regime, the experimental conditions could be restrictive. Indeed, to obtain this diffuse discharge, the gas must be previously pre-ionized before the breakdown. Even if diffuse DBD in air have been observed since the last decade [3-6], the mechanisms responsible for this preionization are poorly understood. This preionization could be related to a surface or/and a volume mechanism.

To understand the origin of this memory effect, first, we compare diffuse discharge obtained with alumina from different manufacturers. The discharge behaviour completely differs depending on the alumina, even if their macroscopic properties are the same.

Then, thanks to a segmented electrode [7], we observe current discharge and gas gap voltage with spatial resolution. We observe that the gas breakdown voltage increases with the increase of the gas residence time. This effect is counterintuitive as it implies a decrease of the memory effect when the gas residence time increases, which is exactly the opposite behaviour of N_2 discharges.

To conclude, there are both surface and volume mechanisms in case of diffuse discharges in air. Some hypotheses are provided and will be discussed to explain these different mechanisms.

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O- 49

Peculiarities of Lissajous Q-V diagrams during power measurements in pulsed SDBDs

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Dielectric-barrier discharges (DBDs) are common media to generate non-equilibrium plasmas. Particularly, in surface DBDs (SDBDs) both electrodes are in contact with a dielectric material and the discharge evolves only on the dielectric surface, unlike volume DBDs [1]. SDBDs garner significant interest across various fields and electrical characterization is thus essential.

This study is devoted to the electric power evaluation in the case of a special SDBD setup, by means of Lissajous Q-V diagrams. Namely, the SDBD setup pertains to a cylindrical configuration comprising two annular stainless-steel electrodes, a quartz dielectric and encapsulating transformer oil for the grounded electrode [2], while it is driven by rectangular positive high voltage pulses. Three different approaches are considered to obtain the Q-V diagrams: (i) use of wideband current transformer, ii) use of shunt capacitor, and iii) use of shunt resistor. The applied voltage is routinely recorded with a high voltage probe in all three approaches, whereas the charge is calculated either by the voltage drop across the shunt capacitor or the numerical integration of the current in the cases of current transformer and shunt resistor. Similarities, differences, and peculiarities for each approach are demonstrated and discussed in detail.

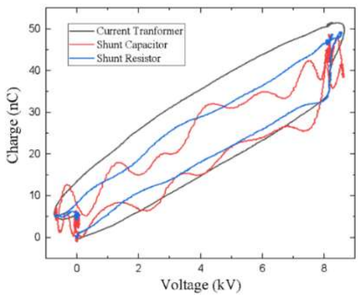

Fig 1. Indicative Lissajous Q-V diagram (V=9 kV, f=10 kHz, t_{on}=160 ns)

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O-50

Electric field measurement of single channel streamers by E-FISH

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Recently, a new technique called electric field induced second harmonic generation (E-FISH) has been introduced to the plasma community to measure the electric field of various kinds of plasmas [1]. Although it has been shown that the measured signals are strongly related to the laser beam profile and to the electric field profile [2], recent advances on the interpretation of E-FISH signals provide us the possibility to restore the electric field distribution of single channel streamers if cylindrical symmetry is assumed. In this work, we measure the E-FISH signals of single channel positive streamers in air and air-like mixtures at pressures around 100 mbar. Figure 1 shows the E-FISH signals of E_y of a streamer in 70 mbar air with an applied voltage of 8 kV at different positions and time delays. The space charge layer with a crescent shape, where the electric field is the most intense, is clearly visible.

The line-of-sight integrated signals are then restored into electric field distributions by a deconvolution method. These results are also compared with existing simulation results and previous OES measurement under the same conditions [3]. More details and the fully processed experimental results will be presented at the conference.

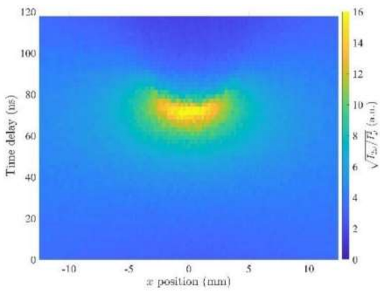

Figure 1. A 2D map of E_y signals of a streamer in 70 mbar air with an applied voltage of 8 kV. The streamer propagates in the y-direction.

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O-51

The characterization of an RF Ar plasma jet operating in controlled O_2, N_2 or air ambient gas

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Atmospheric pressure plasma jets produce various reactive oxygen and nitrogen species (RONS) that have been extensively utilized in different biomedical applications. We have recently shown that the production of Ar plasma jet in controlled ambient gas of O_2, N_2 or air allows to control the RONS composition and it has an impact on the cancer cell viability [1]. The production of RONS is further influenced by plasma parameters, e.g. electron density and temperature, gas temperature. In turn, these parameters are influenced by ambient gas composition and various other parameters, such as feed gas flow rate, applied voltage, and distance between the tube nozzle and liquid surface.

The aim of the present study was to investigate the plasma parameters of an atmospheric pressure radio frequency (13.56 MHz) Ar plasma jet used for the production of plasma-activated water [1]. Plasma was ignited inside a quartz tube from where it extended 5 mm into controlled ambient gas (air, O_2 or N_2) resulting in the ohmic contact with water. In all ambient gases, the generator output power was 50 W. The rotational temperatures of N_2(C,v=0) and OH(A,v=0), were ≈1000 K in the tube and then increased up to 1500 K for N_2(C,v=0) and 2300 K for OH(A,v=0) near the water surface. The broadening of Ar 750 nm line gave similar temperature as N_2(C,v=0) rotational temperature. Electron temperature determined from Ar continuum radiation for O_2 gas was ≈1.7 eV in the tube, decreased outside from the tube to and increased again near the water surface. The electron density determined from Stark broadening of H_α line was ≈10^{15} cm^{-3} in the tube reached a maximum value outside of the tube and then reduced towards the water surface. The density of Ar ($1s_5$) metastable state atoms was determined by Tunable Diode Laser Absorption Spectroscopy, it was ≈10^{12} cm^{-3} in the tube and then decreased towards the water surface. Different ambient gases used in the present work did not influence plasma parameters remarkably while the impact on RONS composition in water was significant [1].

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O-52
Numerical study on the effect of negative corona discharge on droplet emission from Taylor cone

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When a DC high voltage is applied to a liquid in a capillary electrode, the liquid forms a shape of Taylor cone, and droplets are emitted. When the electric field at the Taylor cone tip exceeds the corona onset voltage, corona discharges occur simultaneously. Simultaneous generation of corona discharge and droplets is promising in the application of plasma-liquid interaction [1]. The current waveform of a negative corona discharge with a Taylor cone has multiple current pulse trains with the first pulse in each train having the largest peak, and droplets are emitted synchronizing with this pulse [2]. This suggests that changes in the electric field in pulse current growth affect droplet ejection. In this study, we investigated the effect of negative corona discharge on the droplet emission from Taylor cone by numerical simulation using commercial software, COMSOL Multiphysics.

The time constant of current pulses is less than 100 ns, whereas that of Taylor cone formation is much longer. Therefore, the calculation model was divided into three steps, (i) Taylor cone formation, (ii) corona discharge from Taylor cone, and (iii) droplet emission under electric field by the corona discharge. The electrode geometry considered is shown in Fig. 1. In step (i), mass conservation and Navier-Stokes equations were solved, and the droplet emission with Taylor cone formation was calculated. In step (ii), Trichel pulse discharge was simulated by fluid model, with Taylor cone-shaped electrode taken from a snapshot in step (i). In step (iii), droplet emission was calculated under the dynamic electric field by the negative corona, using the same method as in step (i). The volume force in Taylor cone with corona electric field (Fig. 2) is roughly three times larger than that without corona, leading to the rapid droplet emission.

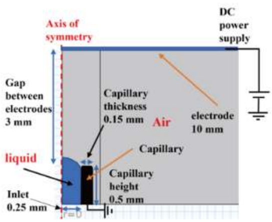

Fig.1 Simulation model.

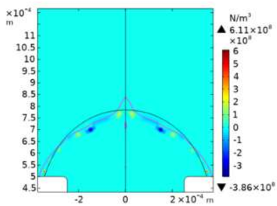

Fig.2 Z-component of volume force acting in Taylor cone with electric field by corona discharge.

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O-53

MERLINO – An efficient 0D solver for non-thermal plasma simulations

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Volume-averaged (global) models are a valuable tool for the study of plasma devices. We introduce Merlino, an efficient 0D plasma code written in matlab. The main goal of Merlino is to be adaptable to a wide set of problems while retaining performances comparable to the ones of codes written in compiled languages, such as the well-established ZDPlaskin software. Reaction rate constants involving electrons can be computed using the Loki B electron Boltzmann solver [1]. The user can specify electrical parameters of an external electrical circuit that can be used to compute the applied reduced field at each time-step, see, e.g., Fig. 1. One unique feature of the code is that two different approaches for the evaluation of the species production terms are implemented. The first is based on generating ad-hoc m-functions in text format, while the other is based on automatic building of a stoichiometry matrix used to compute the species production rates array through matrix-vector products.
We discuss the pros and cons of both approaches, and we perform a performance benchmark for reactions sets of different size and complexity.

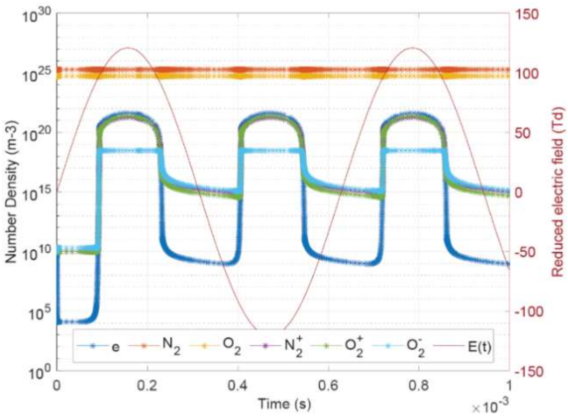

Figure 1. Number densities and applied reduced electric field using the simple dry air scheme from [1]

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O-54

Multi-temperature model for CO_2 non-equilibrium plasmas

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The closure of the carbon cycle and the electrification of the industry, particularly in the production of fuels and valuable chemicals, poses significant challenges. In this regard, plasma-based CO_2 conversion emerges as a versatile and promising technology [1]. However, its industrial application faces hurdles, and its energy efficiency depends on the type of plasma being used [2]. A key factor in improving efficiency is identifying the fundamental processes underlying CO_2 conversion in a plasma, especially those leading to splitting with minimal energy consumption, and optimizing the reactor design accordingly.

To address this, we have developed a 6-temperature kinetic model, solving vibrational energy balance equations for the CO_2 asymmetric and symmetric modes, as well as the CO and O_2 vibrational modes, along with the gas and electron temperature balance equations. In addition to the energy balance equations, the model solves for the temporal evolution of the densities of CO_2/CO/O_2/O, the main electronically excited states, and the dominant ions. The model is successfully validated with pulsed glow discharge eperiments by Klarenaar *et al*. [3] and Damen *et al.* [4]. An innovative aspect is the direct solution of the vibrational distribution functions based on the energy balance (energy approach), assuming a Boltzmann distribution, eliminating the need for computationally expensive state-to-state kinetic schemes. The excellent agreement between calculated and experimental temperature profiles supports its suitability for systems in significant non-equilibrium conditions. This opens new avenues for coupling of a detailed CO_2/CO/O_2/O kinetics with computational fluid dynamics codes, essential tools for reactor optimization and scaling up.

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O-55

Flow Induced by Surface Dielectric Barrier Discharge (sDBD) for Plasma Conversion

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Atmospheric pressure plasmas namely dielectric barrier discharges can be used for carbon dioxide conversion or for, volatile organic compounds removal. Surface dielectric barrier discharge (sDBD) are simple sources and can be made compatible with many industrial applications. One prominent feature of the sDBD is the ionic wind, which is generated by electrohydrodynamic forces leading to the creation of upstream and downstream vortices in the vicinity of the plasma. Since in this study, efficient mixing of the gas flow with the plasma is important due to tiny plasma filaments in sDBD discharges, dynamic behaviour of vortices has been investigated by means of Schlieren imaging diagnostic and fluid dynamic simulation to extrapolate the details of the flow pattern and its interaction with surface discharges. It is shown that efficient mixing of the gas flow with the plasma is essential for good plasma conversion by adjusting the residence time of species in contact with the plasma. This has been studied by monitoring the conversion of one percent CO2 admixed to an N2 gas stream via infrared spectroscopy in the exhaust. The results indicate the influence of gas flow rate on the conversion of CO2 which is in good agreement with the size of vortices created by plasma to explain the phenomena [1].

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O-56

Discrete Ordinates method for capturing photoionization shadows in air streamer simulations

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Numerical simulations of streamer propagation in air, involving photoionization, will be presented. Two approximate methods for radiative transfer are used: the *Eddington Approximation (*EA*)* and the *Discrete Ordinates* (DO) method [1-4], to handle the computation of photoionization source terms. The former (EA) is commonly employed in streamer simulations, while the latter (DO) is well-established in other branches of computational physics, such as radiative heat transfer. A comprehensive 2D test case, featuring two distinct regions where streamer propagation can be independently triggered due to the protruded electrodes, is used [5]. These regions are partially separated by an opaque solid insulator barrier to study the effects of photoionization shadows on streamer inception and propagation. The primary positive streamer is initiated by placing a neutral plasma patch close to one of the electrode protrusions. Meanwhile, the secondary positive streamer, in another region of the computational domain, is initiated by photoionization originating from the primary streamer zone. It is demonstrated that the DO method provides an accurate photoionization distribution by blocking part of the radiation, thus creating zones of photoionization shadow when opaque obstacles are present in the computational domain.

Acknowledgments: The project was partly supported by the Technological Agency of the Czech Republic, Project Number TK04020069.

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Technical contributions

T-01

Atmospheric pressure plasma coating deposition of functionalized thin films as green alternatives for adhesion promotion process

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From an industrial point of view, surface pre-treatment is considered to be an essential step in ensuring adhesion performance over time. This surface preparation process can include several steps such as solvent cleaning, chemical or physical modification of the surface and is designed to increase surface polarity, improve wettability and ensure good adhesion [1].

Atmospheric plasma surface treatment is emerging as one of the most innovative and environmentally friendly technologies in this field. The possibility of reducing the production of volatile organic compounds (VOCs), thus making workplaces safer and production processes more sustainable, makes it a process of great confidence for present and future application. In the first part of this paper, the ability to increase the surface free energy and polarity of polymeric materials and how It may impact from an adhesion performance point of view is presented and analysed, with a comparison to other surface preparation methods [2].

It has been observed that plasma surface activation or plasma cleaning may not be sufficient to provide good adhesion over time, especially when materials are exposed to high temperature and humidity variations. To overcome this challenge, recent research has been focused on combining specific precursor chemistry with plasma reactive species in order to deposit a functionalized thin layer on different materials. This approach aims to create covalent bonding and improve adhesion by forming a strong chemical bond between materials. The most recent results demonstrated that the nanometric layer of plasma deposited at the interface of the material and the adhesive provided excellent adhesion even during climate testing.

The second section of this study will present a comparative analysis of the effects of plasma surface activation and atmospheric thin film deposition on metal. The bonding strengths of coated metal plates with different adhesives will be investigated under dry and climatic conditions using single lap shear tests.

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T-02

Odor mitigation with cold plasma in industrial emission source

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The issue of odor mitigation in industrial applications is becoming, day by day, a source of friction between companies and the neighborhood, whether made up of other companies or home and other civil buildings.
In fact, it is not unusual to come across companies that have a recognized odorous impact on the various stakeholders. Italian decree n°309 of 06/28/2023, also known as MASE decree for odor impacts, is a guideline of actions to deal with these issues.
If from the point of view of reducing polluting emissions into the atmosphere, air control systems are very high performing and have generally low management costs, the use of the same systems to tackle odor reduction, arises in a series of shortcomings both in terms of efficiency aspects and economic sustainability of the investment.
In such cases we are mostly talking about odor mitigation as it is difficult to achieve high returns with sustainable costs for companies.
In fact, it is typical to come across systems such as regenerative thermal oxidizers or multi-stage wet scrubber to address this issue except with significant CAPEX and more over OPEX.
An answer can come from the application of cold plasma which is certainly a more than authoritative technology for dealing with this odorous issue.
What an odor consists of, which chemical groups are present and what the responses of these chemical groups compared to the cold plasma treatment are issues of fundamental importance to fully understand the principle of action of the system.
The research will show how the cold plasma system is able to oxidize the various molecules by studying their behavior as a function of the composition of the odor itself in order to identify a qualitative-quantitative predictive assessment of mitigation based on the chemical groups at the entrance.

T-03

Characterization of a pulsed DC kHz helium jet vs different powers and flow rates, and density spatial analysis of the jet source

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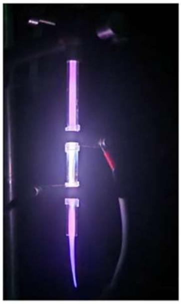

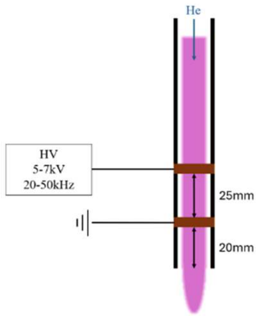

Langmuir Probe measurements have been performed on a Helium Atmsopheric Pressure Plasma Jet (APPJ) to obtain an electron density profile from the source out to the jet. This jet has been characterized over a range of applied voltages (5-7kV) and flow rates of the jet (2 and 4 slm He). This is done with the goal of presenting a methodology for researchers/industries to get reliable measurements of the plasma density from a Langmuir Probe from plasma jets at atmospheric pressure.
These measurements have been compared with optical measurements previously made on the same set up [1]. They are also compared with a fluid/plasma Comsol model for an APPJ of the exact same geometry for theoretical to experimental relatability. This model conducts numerical simulations with a two-dimensional asymmetrical layout to show a spatial plasma density profile of the APPJ. The reactions for this model include not just electron and ion formation, but also metastables and radicals. Metastable reactions have been shown to be a major energy absorber in atmospheric plasmas [2-3].
A Langmuir Double Probe was also utilized for measurements of electron temperature (Te), to compliment the density measurements for use in chemistry models for atmospheric jets.

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T-04

Nadir Dual Frequency Plasma: a versatile device for functional coatings deposition for a wide range applications, from biomedical to green hydrogen production

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The Nadir Dual Frequency Plasma is an atmospheric pressure plasma jet device, utilizing Dielectric Barrier Discharge (DBD), which was developed and patented between 2012 and 2014, and has been available commercially since 2018. The device features two pairs of electrodes, with one set operating at high voltage (HV) around 20kHz and the other set at radio frequency (RF) of 27 MHz. The rapid oscillations of the RF prevent streamer formation and promote the generation of diffused plasma. These advancements enable us to lower the heat impact on the treated surface, while still achieving high plasma density and efficiency. The HV, on the other hand, ensures ignition and stability even at low power levels [1], resulting in one of the coolest plasma sources available.
Moreover, the Nadir device is equipped with an internal coaxial duct allowing the introduction of a wide range of chemicals, both in the vapor or aerosol phase, enabling atmospheric pressure plasma with both vapor and liquid precursors (APPVD or APPLD). In addition, the processes can benefit from pulsing mode with both power supplies to optimise reticulation and preservation of functional groups.
Due to this unprecedent versatility, the Nadir device has been applied in a wide range of studies and applications, from tissue engineering, by creating a functional layer for cell adhesion, proliferation, and differentiation purposes [2], to wood research, by providing coatings with flame retardant properties [3], to the realization of biosensors by providing plasma-polymerized conductive polymers or cross-linked natural polymers such as silk fibroin and chitosan [4]. In conclusion, catalytic coatings produced through plasma polymerization, which utilize pure organic compounds for the chemical sector or pure metallic layers for the preparation of fuel cell membranes and the generation of green hydrogen, will also be introduced.

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Poster communications

P-01

Plasma-assisted ammonia synthesis in a dielectric barrier discharge reactor at various operating conditions

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The need for producing ammonia (NH_3) using alternative processes other than the energy-intensive Haber-Bosch, alongside the potential of NH_3 as an energy vector, has motivated increasing efforts in the plasma community to demonstrate the feasibility of small-scale NH_3 synthesis [1]. Owing to their simplicity and atmospheric pressure operation, Dielectric Barrier Discharges (DBDs) have been widely studied for this application [2-3].

In this work, nitrogen-hydrogen (N_2-H_2) discharges in a coaxial cylindrical DBD were studied over a wide range of inlet flows (25-300 sccm), inlet concentrations (10-75% N_2), discharge lengths (25-80 mm). These conditions allowed varying the specific energy input (SEI) between 10-120 J cm^{-3} and the residence time between 0.4-15 s. The amount of NH_3 produced in the discharges is determined by mass spectrometry. Figure 1 compares the NH_3 concentration in the outlet stream as a function of the N_2 inlet fraction obtained with the reactor empty and packed with γ-Al_2O_3, exhibiting a maximum close to the stoichiometric ratio of 1-3 N_2-H_2. High-resolution optical emission spectroscopy is used to characterize the discharge and gain insights into the plasma chemistry, mainly by identification of species of interest (e.g. N_2, N_2^+, NH, H, N) and determination of rotational and vibrational temperatures of N_2.

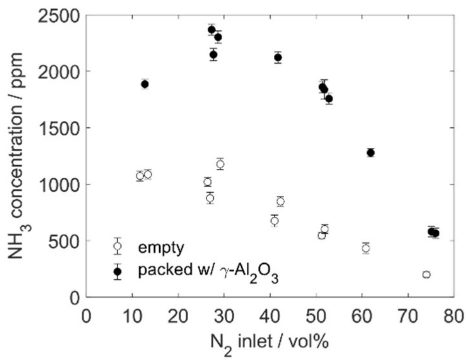

Figure 1 – NH_3 concentration obtained with empty reactor and with reactor packed with γ-Al_2O_3 support pellets for various N_2 inlet concentrations, a total inlet flow of 100 sccm and a constant SEI of 31 J cm^{-3}.

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P-02

Comparative study of the efficacy of nitrogen fixation by various atmospheric-pressure plasma sources

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The ongoing intensive research in the field of electrical discharges in or with water is fueled both by the many unsolved problems concerning the mechanism of such complex discharges and by the possible new applications of plasma-activated water (PAW) related to water decontamination and environmentally friendly synthesis of fertilizers in plasma-assisted agriculture. However, a complete understanding of any discharge system is essential for any optimization or scale-up, which requires a complete characterization of the stable products (both gaseous and aqueous) along with a comprehensive diagnosis of the discharge phase and could benefit from direct comparison between various types of reactors under similar input parameters. In this comparative study, the efficacy of nitrogen fixation in PAW was studied for three atmospheric plasma sources with different interaction geometry of the discharge channels with the water surface: (i) surface DBD (planar plasma source without direct contact with the water surface), (ii) volume DBD (discharge channels perpendicularly impinging the water surface) and (iii) recently developed streamer-based discharge occurring directly at the water-air interface [1-3] (discharge channels parallel to the air-water interface). In the case of SDBD, two energizing methods were also compared (ns-pulses and amplitude-modulated AC). UV-vis-NIR ICCD spectroscopy was combined with electrical characteristics to determine the basic characteristics of the DBD microfilaments, including vibrational distributions and rotational temperatures of nitrogen excited states, the presence of various radicals, and time-resolved analysis of discharge phases. The efficiency in terms of $H_2O_2/NO_2^-/NO_3^-$ production yield was determined in a flow-through reactor under well-defined and stable discharge conditions, where Fourier-transform infrared spectroscopy was used to determine the composition of outlet gas (O_3, N_2O, NO_2, N_2O_5) and ion chromatography was used to analyze the generated PAW. The reactor types proved capable of generating PAW with various NO_2^-/NO_3^- ratios (ranging from balanced 1:1 to almost total dominance of NO_3^-), with production yields ranging from 1 to 5 g/kWh depending on the energizing method, pulse frequency, and air and water flows.

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P-03

Non-thermal plasma induced CO generation from CO_2 studied by operando-DRIFTS: experimental design and first results

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The conversion of the greenhouse gas carbon dioxide (CO_2) to the platform chemical carbon monoxide (CO) by means of non-thermal plasmas (NTPs) is of increasing interest because it can operate at mild conditions and convert fluctuating renewable electricity into chemicals or fuels. The plasma conversion can be significantly enhanced by heterogeneous catalysts (plasma-catalysis)[1,2], but the fundamentals of these processes are not yet fully understood. Diffuse reflectance infrared Fourier transform spectroscopy (DRIFTS) allows the *in situ* analysis of adsorbates on the catalyst surface. Herein, we present the development of a customized NTP-DRIFTS cell, which integrates a miniaturized dielectric barrier discharge (DBD) in an established Harrick reaction cell implemented in a Bruker Invenio S FTIR spectrometer (see fig. 1). The stable operation of AC-driven (10 kHz), filamentary, asymmetric DBDs in binary gas mixtures of argon and CO_2 over several hours is monitored by means of electrical measurements, which also allow the determination of discharge power. The impact of applied high-voltage amplitude under the variation of the gas composition, gas flow, catalyst pretreatment procedure and the distance between electrode and catalyst bed is explored. First results with ceria as a promoter for plasma-induced CO_2-splitting show that oxidative and reductive pretreatment only affects the population of adsorbates with a slight effect on products formation. The variation of CO_2 concentration has no influence on adsorbates formation whereas low flow rates lead to higher population of formate adsorbates.

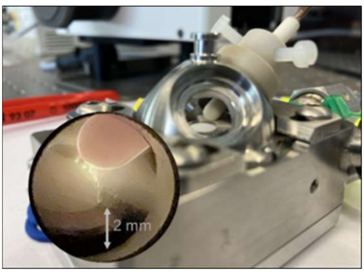

Fig. SEQ Fig. * ARABIC 1: Integration of DBD electrode in Harrick reaction cell.

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P-04

CO_2 conversion in a packed-bed cylindrical dielectric barrier discharge

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The rising levels of greenhouse gas emissions due to continued fossil fuel usage is a legitimate concern for the future of our planet. Plasma-assisted recycling or decomposition of carbon dioxide, one of the main contributors to global warming, is of great interest owing to the possibility of integrating, with relative ease, the plasma technology into the intermittent operation of renewable energy-based power plants. Atmospheric pressure dielectric barrier discharges (DBD) are of interest due to their simple reactor designs. Moreover, the non-thermal nature of the discharge allows to potentially tune the energy transfer into different channels for the efficient processing of CO_2. Use of a packing material in a DBD can improve CO_2 conversions provided the relevant physical (E-field variations) and chemical (catalytic interactions) effects are optimised. Focusing only on physical effects, studies have shown that packings with higher dielectric constant result in a positive influence owing to the enhanced local E-fields that lead to an increase in electron temperatures followed by increase in conversions presumably via electron impact dissociation of CO_2. However, this is not necessarily true under all conditions as the interelectrode gap and the packing bead size also play a role [1]. Furthermore, partial discharging is a common phenomenon in packed bed DBDs where the discharge is spatially limited and localized, and the entire gap does not partake in ignition [2]. This, for instance, will affect the real residence time in the discharge, thereby making the comparison of packing materials complicated. In this work, we investigate a coaxial cylindrical DBD for the conversion of pure CO_2 with and without a dielectric packing, with no catalytic effect. An interelectrode gap of 3 mm and a discharge length of 22 mm are used. Compared to the empty reactor, for a given power of 36 W and flow of 5 sccm, results show an increase in conversion from 10 to 14 % with both an Al_2O_3 and quartz packing, despite the reduced residence time from 4 to 2 s. This is attributed to the dominant effect of the increased power density and the enhanced local electric field in the packed bed reactor. While applying insights from literature, we aim to perform a systematic study of the aforementioned physical effects on the CO_2 conversion by varying parameters such as the packing dielectric constant, gas flow rate, interelectrode gap and discharge power.

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P-05

Hydrogen production from decomposition of ethanol using a non-self-sustained plasma discharge at atmospheric pressure: Hydrogen selectivity and energy efficiency evaluation

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Today, hydrogen stands out as one of the most strategically important substitutes for carbon-based fuels, offering numerous advantages. These include a reduction in reliance on finite reserves of fossil fuels, mitigation of the greenhouse effect by minimizing CO_2 emissions, and the release of more energy during combustion compared to traditional fuels [1]. However, over 95% of the current hydrogen production stems from fossil fuels, predominantly through steam methane reforming (SMR), an energy-intensive process that generates substantial quantities of CO_2. Hence, there's a growing interest in exploring alternative techniques, such as leveraging plasma sources. Non-thermal plasmas (NTPs) have emerged as a promising avenue for hydrogen production through the decomposition of hydrocarbons, alcohols, and various polymers, given their CO_2 neutrality and compatibility with renewable energy sources [2]. NTPs can efficiently dissociate almost any H-rich compounds into molecular hydrogen and other valuable products such as C_2H_6 and CO. Among H-rich feedstocks, ethanol has captured researchers' attention due to its derivation from renewable bio-ethanol obtained from biomass. However, enhancing the conversion efficiency and selectivity of this process remains of importance. Within the realm of NTPs, non-self-sustained plasma discharges, operating at atmospheric pressure, are known to prevent instabilities and create large-volume plasmas crucial for chemical reactions [3]. Nonetheless, they represent a relatively underexplored yet promising frontier for hydrogen generation from ethanol.

In the current study, we employ a plasma discharge operated in a non-self-sustained regime for ethanol decomposition into molecular hydrogen. Ethanol in the gas phase is introduced into the discharge and the resulting decomposition products are analyzed using gas chromatography. We investigate the impact of different gas flow rates on the gas vortex inside the reactor. Moreover, we explore ethanol decomposition under various atmospheres such as argon and nitrogen. Our findings reveal complete ethanol decomposition, with hydrogen being the predominant product detected by gas chromatography, alongside other compounds such as CO, CO_2, carbon black, CH_4, and C_2H_6. Furthermore, we determine key parameters like energy yield and selectivity across a wide range of experimental conditions.

This research is supported by the Excellence of Science FWO-FNRS project PLASyntH2 (EOS ID: 40007511)

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P-06

Non-thermal plasma with photocatalysis for bacteria decontamination and VOC removal from indoor air

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Long-term exposure to indoor air pollution is responsible for respiratory, cardiovascular, and oncological diseases, which is a major public health issue. Hospitals-acquired infections are also spread through air contaminants, e.g. pathogenic aerosols [1]. Finding an innovative technology that would efficiently remove all kinds of airborne pollutants without producing harmful by-products and with a low energy cost would be not only a major advance for public health but would also help preventing the spread of airborne pathogens such as in the case of the recent COVID-19 pandemic. The goal is this work is to assess the efficacy of non-thermal plasma (NTP) combined with photocatalysis for the removal of VOCs and inactivation of aerosol-borne bacteria at a high gas flow rate. NTP and photocatalysis have proven their capabilities to decompose or inactivate a broad range of harmful compounds present in indoor air. Moreover, combining these two techniques may offer a very effective hybrid air decontamination device, as studies suggest a synergetic effect [2].

We designed an indoor air decontamination device that combines a Dielectric Barrier Discharge (DBD) for the NTP generation and a TiO_2 coating which is activated by UV-A LEDs. Despite a very short residence time of the pollutant in the reactor (gas flow rate was set above 300 L/min), we obtained the removal efficiency of about 40% for VOC decomposition with a single-pass in the reactor. We also studied the inactivation of *E.coli* and *S. aureus* using a single-pass method. The bacteria were first prepared in solution and then sent in the reactor in a form of bioaerosols. The decontamination efficiency of these bio-aerosols are also very promising, for both bacteria, almost 100% of inactivation was reached. We also varied the duty cycle of the discharge and found very good results at a low duty cycle (15%), thus reducing the by-product ozone concentration.

This work was supported by Slovak Research and Development Agency APVV-17-0382, APVV-22-0247, and APVV-20-0566, and a postdoctoral support of Comenius University Bratislava.

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P-07

NO_x removal by discharge in honeycomb monolith

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To mitigate the environmental impacts of exhaust gas pollutants, reducing NOx emissions from diesel engines is imperative. This can be achieved through the implementation of emission control technologies, adoption of cleaner fuels, and promotion of sustainable transportation practices. The ability of non-thermal plasma generated by electrical discharges to create high-reactive environment at ambient conditions has found vital role in exhaust gas treatment. Synergetic effect of plasma discharge and honeycomb catalyst paved the feasibility to integrate SCR for effective NO_x reduction [1]. NTP flue gas cleaning technologies has good efficiency of NO_x removal, due to the formation of the reactive species such as O, OH, O_3 during the NTP generation process [2]. Many authors reported with the honeycomb monolith reactor that the removal efficiency can be improved by increasing the ozone species concentration [3,4]. However, the high specific input energy (SIE) led to an increase in the local concentration of ozone, promoting the oxidation of NO_x [5]. Instead introducing new catalytic material for NO_x removal, enhancing the plasma discharge relatively easy to adapt in existing plasma technologies.
In this work we used honeycomb reactor consisting of a ceramic honeycomb monolith placed between a multi-needle electrode and a perforated metallic electrode to generate plasma discharges. The discharge was driven either by DC and AC high voltages. The chemical activity of the discharge was influenced by the airflow rate and humidity of the air, resulting in the highest concentrations of products. This work aims to observe the impact of humidity and flowrate in accordance with the electrical characteristics of honeycomb reactors, NO_x removal efficiency (in %) and energy efficiency (SIE) (kWh/g). The chemical activities of gaseous products of the NO_x removal were examined using infrared absorption spectroscopy (FTIR) as a diagnostic methodology.

This work was supported by grants of Slovak Research and Development Agency APVV-20-0566 and Slovak Grant Agency VEGA 1/0822/21 and the EU NextGenerationEU through the Recovery and Resilience Plan for Slovakia under the project No. 09I03-03-V02-00036.

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P-08

Degradation of Benzene by micro-discharge plasma formed in Mn-Ce loaded porous ceramics

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The catalytic oxidation of gaseous benzene in a micro-discharge plasma catalytic reactor was investigated in this work. Micro-discharges could be generated continuously by applying a voltage to porous ceramics (PCs) in previous studies[1]. PCs/Mn-Ce, PCs/γ-Al_2O_3 and PCs/γ-Al_2O_3/Mn-Ce catalysts were prepared and packed in the electric discharge zone separately. The obtained results showed that γ-Al_2O_3 coating improved the catalytic performance of MnO_x/CeO_2 catalysts on porous ceramics for benzene degradation, and MnO_x/CeO_2 composites presented higher benzene degradation efficiency, CO_2 selectivity and lower O_3 byproducts. In addition, PCs/γ-Al_2O_3/Mn-Ce catalysts were beneficial to enhance the energy efficiency of benzene degradation, but the energy efficiency of benzene degradation decreased with the SIE, All catalysts were characterized using N_2 adsorption, XRD, SEM, H_2-TPR, and XPS. The results verified that the PCs/γ-Al_2O_3/Mn-Ce catalysts had larger BET surface, better dispersity, superior redox properties and more oxygen mobility, which might contribute to the synergistic effects among the γ-Al_2O_3, MnO_x and CeO_2 for the synergistic catalysis. Porous ceramics with pores of micrometer size are capable of enhancing the degradation of gaseous benzene via the reactive species in-situ produced by micro-discharge in the pores of ceramics. γ-Al_2O_3 coated on the porous ceramics is able to enlarge the adsorbing interface, and Mn-Ce composites loaded onto the porous ceramics can improve the benzene degradation and reducing the ozone concentration. Therefore, modification of PCs by Mn-Ce catalysts and Al_2O_3 can efficiently degrade benzene in micro-discharge plasma. This research, which combined micro-discharge and Mn-Ce catalysts to efficiently degrade benzene, provides a novel approach for environmental pollution control.

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P-09

The influence of gas flow rate on a helium DBD via the impurity level

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Here we present a systematic experimental study of the influence of gas flow rate on a helium dielectric barrier discharge (DBD). Due to the imperfections of the sealing and gas supply, along with the surface adsorptions, impurities are always present in the working gas [1,2]. Both in the experiments [3] and numerical simulations [1,4] it was shown that even traces of impurities have a significant influence on the discharge behavior. On the other hand, it is commonly presumed in DBD, that impurity level decreases with increasing gas flow, since the amount of pure gas introduced from the gas container per unit time increases.

To investigate the above-mentioned connection between the gas flow rate, impurity level, and consequential change in the discharge operation, a closed-chamber barrier discharge with plane electrodes was examined via electrical and spectroscopic measurements for a set of gas flow rates varying from 0.05 l/min to 5 l/min. A method was developed for estimation of impurities level from the emission spectrum and applied in the experiment. The method is based on the intensity ratio of prominent nitrogen molecular band and strong helium line. The measurements showed a strongly non-linear decrease of impurities concentration with increasing flow rate of the working gas. A significant change of electrical properties was observed, like breakdown voltage and current density, while the electric field distribution did not show important change. The increase of the gas electrical capacitance with gas flow rate was detected. The space-time development of certain optical emissions indicated the change in the excitation process. The main mechanism of the observed changes with gas flow rate, is the decrease in impurities, which leads to the reduction of helium metastable quenching which, in turn, increases the density of helium metastables important for ionization and excitation processes [5].

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P-10

Chemical effect of Ultraviolet radiation on plasma activated water by transient spark plasma

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Non-equilibrium plasma discharges at atmospheric pressure are used in microelectronics, polymer deposition, light sources, medicinal applications, and environmental remediation [1–3]. Biomedical uses of cold atmospheric plasma produced in ambient air are emerging due to their unique features. Both long-lived and short-lived reactive oxygen and nitrogen species (RONS) are produced by non-equilibrium plasma in the air atmosphere.

On the other hand, UV radiation is commonly employed for water and air purification, medical sterilization, food and beverage sector, and analytical methods [4–6]. The goal of this research is to better understand how cold air plasma interacts with liquid and the impact of UVA radiation as a supporting factor on the production of specific RONS in water. Our investigations specifically examined RONS produced by transient spark (TS) discharge plasma combined with UV radiation in water (H_2O_2(aq), O_3(aq), nitrites NO_2^-(aq), nitrates NO_3^-(aq)), as well as electrical conductivity, pH and Oxidation-Reduction Potential (ORP). Figure 1 shows the schematic diagram of our UV/ plasma setup. Different modes of treatment are examined including plasma alone, UV alone, plasma and UV, plasma followed by UV, and reverse. Photolysis effect of UV in the plasma+UV and plasma then UV treatment is examined by measuring OH and ONOO- in water by fluorescence spectroscopy.

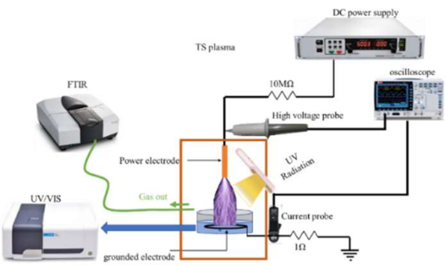

Fig. 1 schematic of UV/plasma setup

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P-11

Optical emission spectroscopy of DBD plasma and diffusion flame atomizers

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Chemical generation of binary hydrides or cold vapours is an efficient approach to analyte introduction into atomic spectrometric detectors to determine selected elements at trace levels. Atomizers based on heated quartz tube, dielectric barrier discharge (DBD) plasma or diffusion flame (MDF) are typically employed in atomic absorption and atomic fluorescence spectroscopy for dissociation and atomization of generated volatile compounds [1]. Limits of detection down to ng ml^{-1} can be achieved with relatively simple and cheap instrumentation.

In this contribution, the DBD plasma and DF atomizers were studied by phase-resolved optical emission spectroscopy employing time-resolved ICCD technique. The DBD atomizer was powered by high frequency square wave power supply and operated at atmospheric pressure in argon. Traces of Hg and Cd present in liquid standards as Hg^{2+}, CH_3HgH^+ and Cd^{2+}, respectively, were efficiently converted by $NaBH_4$ reduction to volatile Hg^0, CH_3HgH and Cd^0. A significant amount of H_2 is produced and transported into the atomizer.

Whilst the spectral lines of argon were synchronized with the DBD discharge current according to the expectations, analyte lines (Cd at 508 nm and Hg at 254 nm) were substantially delayed. The exception was Hg I line at 546 nm, which quickly followed the argon emission. This suggests either self-absorption of the 254 nm line or an indirect mechanism for excitation of the upper state of 546 nm line. H_2 continuum, dominating the spectrum in UV range, appeared in time between the 546 nm line and the resonance 254 nm line. The time-resolved emission spectra of Hg showed the same behaviour, even for 546 nm line, regardless Hg^0 or MeHgH species were introduced into the discharge suggesting similar excitation mechanism. Excitation mechanism of Cd will be discussed.

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P-12

Observation of spatiotemporal distribution of surface charge density on alumina barrier during atmospheric pressure Townsend discharge in air

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Atmospheric pressure Townsend discharge (APTD) is a promising technology for homogeneous surface treatment, CO_2 conversion [1], etc. In 2011, we succeeded in generating APTD even in air using a specific alumina barrier [2]. From observing current waveform and surface charge density, we considered that the surface charge density on the alumina barrier before APTD plays an essential role in the stable generation of APTD in air. In this work, we measured the spatiotemporal distribution of surface charge density generated by APTD in air using a newly developed time-resolved surface charge density distribution analysis method.

Fig. 1 shows the spatiotemporal distribution of surface charge density. The surface charge density at the 0 mm position (directly below the 10 mm diameter high voltage electrode) gradually increased from -24 nC/cm^2 to 8.7 nC/cm^2 when APTD in air was generated between 22° and 90°.

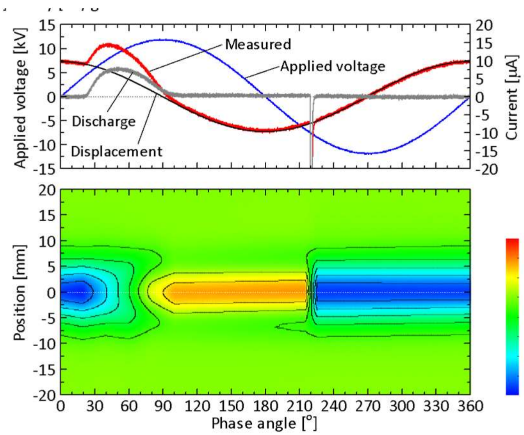

Fig. 1 Spatiotemporal distribution of surface charge density.

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P-13

Degradation of propranolol by water falling film DBD reactor in different atmospheres

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The study of low-temperature plasmas in contact with liquids has evolved as a new interdisciplinary research field driven by the development of plasma applications for water purification, biomedicine and agriculture. Electrical discharges in contact with liquids are a rich source of reactive species in gas and in liquid phase which can be used to break polluting compounds in water [1]. Pharmaceutical compounds have been detected frequently in surface and ground water at very low concentrations, but due to their persistence and biological activity they represent a considerable health and environmental risk. Propranolol (PRO) is a widely used beta-blocker commonly prescribed for heart -related diseases and anxiety symptoms. Due to its frequent use, PRO is detected in numerous aquatic environments and organisms [2]. For complete removal of PRO advanced oxidation processes or electrochemical oxidation are often used. This work presents the first study of PRO degradation by non-thermal plasma. Water falling film dielectric barrier discharge (DBD) reactor is used for treatment of PRP solution in different gas atmospheres at atmospheric pressure [3]. Water solution of PRO with initial concentration of 100 mg/L is treated in DBD generated in air, argon and argon/oxygen mixture with variation of discharge parameters in order to optimize PRO degradation. The role of reactive oxygen species is investigated by radical scavenging experiments involving t-butanol and p-benzoquinone. Moreover, degradation products are determined and degradation pathways of PRO are proposed. Complete removal of PRO by plasma treatment is achieved in all feed gases.

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P-14

Study of the effect of volume in the treatment of solutions containing organic contaminants in a RAdial discharge Plasma (RAP) reactor

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Atmospheric plasma has recently demonstrated to be able to degrade even the most recalcitrant organic contaminants in water. The radial discharge produced in argon by a new electrode configuration, consisting of a pointed rod as the active electrode and a grounded ring placed at the interface between the gaseous and liquid phases, patented by our research group, can, for example, completely remove 40 ppb of perfluorooctanoic acid (PFOA) in 30 mL of tap water in 2.5 minutes [1]. Scaling-up of this system is highly desirable and would allow its real application in the water purification field. A new RAdial discharge Plasma (RAP) prototype has thus been developed in our laboratory in which up to 400 mL of solution can be treated. The reactor consists of a vertical tube along which the grounded ring can be moved and fixed to change the treated volume and to study the effect of volume on the contaminants degradation efficiency. This study was performed on PFOA, metolachlor and phenol by changing the solution volume from 100 to 400 mL, maintaining constant the initial concentration or the initial amount of the contaminant and bubbling, during the plasma treatment, a flow of argon from the bottom into the solution.
Results showed that the effect of volume depends on the contaminant. This was ascribed to the fact that physical and chemical properties of the contaminants contribute to determine the active volume during the plasma process and the reactive species responsible for their degradation. PFOA showed a very peculiar behaviour, which was attributed to its surfactant character and to its inertness versus OH radical [2-4], while in the case of metolachlor and phenol the process was slower as the solution volume was higher, as expected. Kinetic modelling is currently underway to confirm the proposed mechanistic hypotheses.

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P-15

Investigation of atmospheric plasma treatments for the degradation of perfluorinated carboxylic acids adsorbed on granular activated carbons

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Perfluorooctanoic acid (PFOA) and perfluorobutanoic acid (PFBA) belong to the group known as per- and polyfluoroalkyl substances (PFAS), a class of anthropogenic compounds that recently have been defined "forever chemicals" due to their persistence in the environment [1]. They are toxic towards human life and the ecosystem and PFOA is also classified by IARC as a carcinogenic substance (Group 1). To date, the PFAS removal technique mainly used in the water treatment plants involves their adsorption on granular activated carbons (GAC), which, once exhausted, are subjected to thermal regeneration or destruction [2], with the risk that, if the temperature is not high enough, PFAS are released in air [3]. Moreover, thermal treatment causes loss of carbon and changes in the porous structure of the adsorbent material making regeneration possible for a limited number of times. New advanced techniques able to desorb and degrade PFAS from GAC maintaining intact the adsorption properties of the adsorbent material are thus highly desirable. To this aim, application of atmospheric plasma was investigated in this study. GAC saturated with PFOA or PFBA were immersed in water and treated for 30 minutes using two different electrode configurations and testing both positive and negative polarity of the high voltage electrode. The process was characterized by analysing the final solution by HPLC/ESI-MS, the treated GAC by Thermal Gravimetric Analysis (TGA) and carrying out solvent desorption and analysis of the PFAS remained adsorbed on GAC at the end of the treatment. Formation of hydrogen fluoride/fluoride ions was, moreover, measured by an ion selective electrode allowing to determine the degree of PFOA and PFBA mineralization.

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P-16

Development of a plasma technology for the regeneration of granular activated carbon (GAC) containing PFAS

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Per- and polyfluoroalkyl substances (PFAS) are man-made chemicals classified as Persistent Organic Pollutants (POPs) by the Stockholm Convention [1], often referred to as "forever chemicals" due to their extreme resistance to degradation and their propensity to accumulate in the environment and bioaccumulate within ecosystems.
In water treatment plants, PFAS are generally removed by adsorption on granular activated carbon (GAC). However, once these filters become saturated, they are regenerated through thermal treatment, with the risk of release of PFAS into the atmosphere.
This study explores the development of an atmospheric plasma process as an alternative for desorption and degradation of PFAS from GAC. A reactor employing a dual-frequency plasma system, combining low-frequency (LF 15 kHz) and radio-frequency (RF 27 MHz) voltages was designed as a packed bed dielectric barrier discharge (DBD) coaxial quartz tube, featuring an internal stainless steel rod LF electrode and an external copper tape covering the sample area as ground or RF electrode. Plasma was characterized electrically and by optical emission spectroscopy (OES). Pristine GAC and GAC containing perfluorooctanoic acid (PFOA) and perfluorobutanoic acid (PFBA), used as models of PFAS, were treated using both dual-frequency and single low-frequency modes for 20, 40, and 60 minutes. First results of the analyses aimed to characteriza plasma treated GAC and assess the effectiveness of the processes will be presented.

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P-17

Oxidation of Microcystin-LR by air atmospheric plasma: process efficiency and degradation products

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Cyanobacteria are unicellular photoautotrophs responsible for producing secondary metabolites, including toxic cyanotoxins as microcystins (MCs), in response to different environmental stress factors. Microalgal blooms have been frequently reported in overly enriched bodies of water worldwide, phenomenon that is expected to increase in surface water due to climate changes and eutrophication. Harmful cyanobacterial blooms represent a growing public concern from an environmental and health perspective. WHO already established a value of 1.0 µg/L as a guideline for the intake of total microcystins (MCs) in drinking water [1], and new provisional values for other cyanotoxins have been proposed recently.
One of the most common MCs, and the one most studied, is microcystin-LR (MC-LR), a cyclic heptapeptide characterised by the presence of the unique Adda amino acid that is responsible for the toxicity expressed by inhibited activity of the protein phosphatases type 1 and 2A (PP1 and PP2A) [2]; in 2006, IARC classified MC-LR as a possible carcinogen (Group 2B).
In this scenario, Advanced Oxidation Processes (AOP), and in particular atmospheric plasma, represent an interesting approach to treat cyanobacteria contaminated water [3].
In this study two different plasma systems were employed in the treatment of MC-LR dissolved in tap and Milli-Q water: one based on a Dielectric Barrier Discharge (DBD), the other on a Multipin Corona Discharge (MCD). Treated samples were subjected to targeted and untargeted LC-MS^n investigation. While both the plasma systems were able to remove MC-LR in few minutes, a significant effect of the plasma system and of aqueous matrix was found on the removal of the formed degradation products. These results have been razionalized through the aqueous matrix characterization and the measurement of the reactive species.

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P-18

Recent developments in plasma processing of functional materials for electronic and energetic sectors

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At the beginning of the 21st century, the plasma treatment of materials, including the use of non-thermal plasma at low and atmospheric pressure, has become a critical technology for several of the largest manufacturing industries in the world, including in particular electronics, aerospace, automotive, steel, biomedical, and toxic waste management [1, 2].

The paper summarizes the latest developments in plasma processing of functional materials for electronic and energetic sectors. Appropriate physico-chemical properties of the energetic functional materials are designed and developed for specific application purposes such as solar energy conversion, hydrogen generation and storage, fuel cell design, energy harvesting, etc. [3, 4].

Plasma in surface treatment applications is typically produced in limited quantities and is designed to interact with surfaces that can be dielectrics, metals, polymers, or biological matter [5]. The material being treated interacts with ions, radicals, excited neutral species, and plasma-produced photons that can be used to grow, etch, or modify surfaces or surface reactions in plasma catalysis.

The most important is the electronics industry, where low-temperature plasma is used to produce high-integration microelectronic systems. It is also used to produce diamond layers and superconducting materials. Plasma processing of materials allows the designing, manufacturing, and manipulating of advanced atomic-scale structures [5]. For various ferromagnetic metals and perovskite-type oxides that can be used in magnetoresistive and resistive random-access memories, new technologies such as etching and vacuum deposition are sought to improve the synthesis control and their efficiency significantly.

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P-19

On the use of volume dielectric barrier discharge for the treatment of transparent electrode for organic photovoltaics

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In the last decades, non-equilibrium cold atmospheric pressure plasma has led to numerous opportunities for material treatment. Depending on the gas mixtures, the electrodes configurations, the electrical waveform used to generate the discharge, or the material to be treated, the surface properties of any material in contact with the plasma can be tuned. Among the plethora of applications, the organic photovoltaic (OPV) community has recently explored the use of plasma [1]. Using the various types of plasma-surface interactions, such as etching, deposition, cross-linking, or functionalization, the surface of the different layers can be modified to improve the interface properties and optimize the charge transfer [2]. In this sense, different types of plasma sources have already been used for such modifications. However, the use of classical volume dielectric barrier discharge (V-DBD) has been poorly investigated, the research being mostly focused on plasma jets, RF torch, microdischarges, or surface DBD [3].

In this context, this work focuses on the use of two plasma sources, generated with different electrical signals, to modify the surface of the transparent electrodes (indium tin oxide (ITO) and fluorine tin oxide (FTO)) used in OPV. The surface modifications were studied by X-ray photoelectron spectroscopy, four-point probe measurements and atomic force microscopy. For a better understanding of the induced modifications, electrical measurements as well as optical emission spectroscopy were also conducted *in situ* in the plasma during the treatment, and the results were correlated with the observed properties of the surface.

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P-20

Exploring the effect of key parameters in atmospheric-pressure plasma polymerization for layer deposition

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Preparation of thin, functional, polymer-like layers is an important process in various industries. Plasma polymerization (PP) allows for deposition of such layers using a non-thermal plasma source. The properties of PP-layers are affected by working conditions such as exposure time, flow rate, temperature, substrate properties, input power, electrode system configuration etc. This allows for a more precise customization of layer properties compared to traditional polymerization [1]. However, this flexibility also introduces challenges for experiment reproducibility, as minor parameter variations can negatively impact the PP results. Despite extensive research, the specific effects of each parameter on layer properties and their significance remain unclear, highlighting the importance of further investigation of PP.

This contribution focuses on studying the properties of layers deposited by PP of hexamethyldisiloxane (HMDSO) using a Diffuse Coplanar Surface Barrier Discharge (DCSBD) at atmospheric pressure. Building on previous work in this field [2,3], our objective is to investigate how changes in working conditions impact the functionality, thickness and chemical composition of the deposited layers. Surface diagnostics such as water contact angle measurements (WCA), profilometry, scanning electron microscopy (SEM) and attenuated total reflectance Fourier-transform infrared spectroscopy (ATR-FTIR) are employed to characterize the prepared layers. Ageing tests were conducted to assess the long-term performance of the layers.

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P-21

Nonthermal Plasma Regeneration of Deactivated Catalysts

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The combination of nonthermal plasma (NTP) with catalysis, known as plasma catalysis, is widely used in many environmental applications including the removal of air pollutants [1]. However, the catalysts usually deactivate over time, which limits their lifetime and requires regular regeneration or replacement. Since the replacement of the catalyst is relatively expensive, there is a growing interest in its regeneration [2]. Regeneration of deactivated catalysts can extend their lifetime, thereby increasing their economic profitability [3].
Our research is therefore focused on the potential of NTP generated by packed-bed dielectric barrier discharge (PB-DBD) reactor at atmospheric pressure to regenerate deactivated catalysts. The procedure of the experiment consisted of two steps. Firstly, a model pollutant (toluene) was removed from the air using the PB-DBD reactor. The process resulted in catalyst deactivation due to gradual accumulation of solid compounds on its surface. Secondly, the deactivated catalyst was regenerated in the same PB-DBD reactor in pure oxygen. The experiment was performed for different catalysts (TiO_2, Pt/γAl_2O_3 and Pd/γAl_2O_3). The gaseous products of the toluene removal as well as the products of the regeneration were monitored using infrared absorption spectroscopy (FTIR). The efficiency of plasma regeneration was compared with other regeneration techniques (ozone and thermal regeneration). Moreover, a sequential plasma regeneration (where the catalysts were mixed after a certain regeneration time) was also performed and showed the highest efficiency.
Time courses of concentrations of gaseous products of regeneration (CO_2, CO, HCOOH), thermogravimetric analysis (TGA) and scanning electron microscopy (SEM) were used to evaluate the regeneration efficiency. The analysis of solid compounds on the surface of the catalysts was carried out by gas chromatography coupled with mass spectrometry (GC-MS).

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P-22

Synthesis of metal/polymer nanocomposite thin film by using an aerosol-assisted atmospheric pressure plasma process

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Low-temperature atmospheric pressure plasma technologies offer unique opportunities for the synthesis of hybrid nanocomposite thin films consisting of inorganic nanoparticles (NPs) embedded into an organic matrix. Recently, some studies have shown that it is possible to deposit them by combining plasma processes with an aerosol of gold NPs dispersed in a solution [1].

As suggested in previous work [2], a dielectric barrier discharge (DBD) in nitrogen is associated with an aerosol of a solution of gold salt (tetrachloroauric (III) acid trihydrate, HAuCl4·3H2O) dispersed in a polymerizable solvent (isopropyl alcohol). This process's novelty mainly resides in the fact that it enables the synthesis of the NC thin films in a single step, avoiding the direct handling of NPs.

For the synthesis of nanocomposite layers with a DBD at atmospheric pressure, a dual-frequency excitation is typically used to control independently the growth of the matrix and the transport of the nanoparticles [2,3]. In our study, a high-frequency excitation (above 10 kHz) is necessary for the gold salt reduction to form Au NPs and for the organic matrix growth. On the contrary, low-frequency periods (typically below 1 kHz) are needed to avoid nanoparticles being trapped in the gas gap and, therefore, to favour their transport to the surface of the substrate.

Preliminary results have shown that we are able to synthesize nanocomposite thin films with the inclusion of gold nanoparticles in an organic matrix, deriving from plasma polymerization of isopropyl alcohol. Chemical composition, morphology and optical properties of the resulting nanocomposite layers have been investigated using various characterization techniques, such as Fourier-transform infrared spectroscopy, X-ray photoelectron spectroscopy, scanning electron microscopy and UV-visible absorption spectroscopy.

Overall, these results provide new insights into the possibility of using a single-step aerosol-assisted plasma process to deposit hybrid nanocomposite coatings.

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P-23

Plasma-activated electrolysis synthesis and properties of Cu/Zn oxides nanostructures for sensing applications

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The development of novel composite nanomaterials has recently significantly contributed to the advances reached in the fields of electrochemical sensors and biosensors. The efficiency of the sensors produced is determined by several major parameters, including composition, structure and morphology of the constituent nanoparticles (NPs) and their surface. All these parameters are largely determined by the synthesis conditions of nanocomposites. Herein, to provide the control over the major NPs parameters, a low-temperature plasma-activated electrolysis method has been developed and implemented for the synthesis of metal oxide NPs (CuO, ZnO) and oxide-based composite thin films. In the proposed synthesis method (Figure 1a), metal plates of copper and zinc are used as solid precursors submerged in distilled water while NPs generation occurs in result of a solid metal precursor dissolution after high voltage application (3 kV, current 4 mA) between the combined anodes-precursors and a hollow capillary cathode with Ar flowing through it. The distinctive feature of the proposed approach is anodic dissolution of the solid metallic precursors with a simultaneous electrodeposition of the formed NPs on the surface of the additionally introduced conducting substrate. The developed approach has shown to be efficient for the synthesis of the composite metal oxide nanostructured thin films that due to their optical and electric properties are promising for sensors and biomedicine. The analysis of the formed nanostructured thin films morphology, structure and composition allowed to select carbon and copper substrates as optimal for fabrication of electroanalytic sensor electrode. The work was supported by the by the Belarusian Foundation for Fundamental Researches under Grant No. F 22SRBG-008.

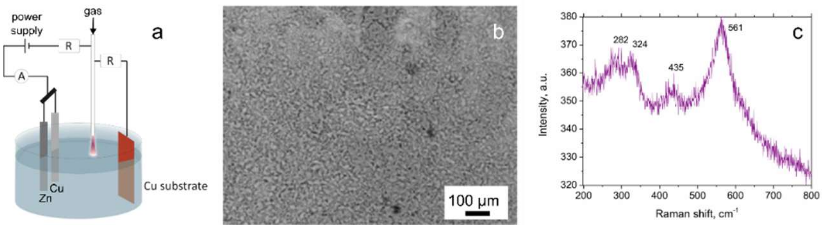

Figure 1. Plasma activated electrolysis synthesis and properties of Cu/Zn oxides nanostructures: a – scheme of the experimental setup, b – SEM image and c - Raman spectrum of the NPs deposited on the copper substrate.

P-24

Sterilization Properties of Surface Materials of Spacecraft by low-pressure and RF Water Plasma Contributing to Planetary Protection

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1. Introduction. In recent years, research on oxygen plasma sterilization methods that do not use chemicals as sterilants has been actively conducted [1]. When using oxygen plasma sterilization inside a spacecraft, where it is difficult to secure supplies, a large amount of cost and storage space is required to transport oxygen cylinders from the ground to the spacecraft. The purpose of this research is to clarify the characteristics of low-pressure water plasma sterilization, which uses water as a raw material because it is a liquid at room temperature and pressure and is easy to carry, and is expected to have high material compatibility. Sterilization properties and material compatibility for polyimide film that is frequently used in spsacecraft are investigated using low-pressure water plasma sterilizer.

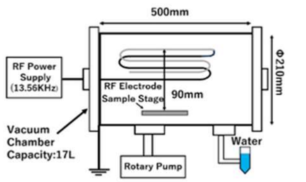

Fig. 1 Schematic diagram of experimental setup

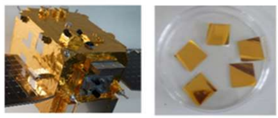

Fig. 2 Polyimide firm covering space crafts.

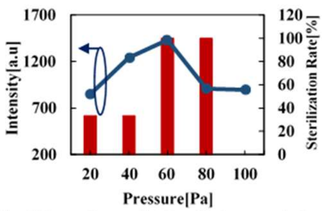

Fig. 3 Dependence of OH radicals on emission intensity and polyimide film sterilization rate on water vapor pressure.

2. Experimental apparatus and method. A schematic diagram of experimental equipment is shown in Fig. 1. High-frequency electrodes were installed along the inner wall of the vacuum chamber to supply high-frequency power (13.56 MHz) to generate capacitive coupled plasma. pure low-pressure water plasma was generated by direct vaporization of liquid water. In an experiment on the sterilization characteristics of water plasma, a sample obtained by applying 2.0×10^6 pieces of thermophilic bacteria *(Geobacillus stearothermophilus*) to a 2 cm ×2 cm polyimide film was used, and the water vapor pressure was changed from 20 Pa to 100 Pa to investigate the pressure dependence of the sterilization rate. Figure 2 shows the sample polyimide firm (Apical film) to be treated.

3. Results and discussion. Figure 3 shows the sterilization results and the change in water vapor pressure of the light emission intensity of OH radicals. At a plasma irradiation time of 180 min, sterilization of all samples was confirmed at pressures of 60, 80 Pa. On the other hand, at a pressure of 20 Pa, the sterilization rate was 30%, and at 40, 100 Pa, it was impossible to sterilize the sample. From the above results, it was clarified that the main sterilization factor for water plasma sterilization is OH radical, and the most suitable water vapor pressure condition for sterilization is 60 Pa. The surface of the material after the irradiation with water plasma had a high chemical bond abundance, and it was confirmed that the high compatibility of water plasma with the polyimide film was confirmed.

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P-25

Effects on physicochemical properties of mung bean by oxygen plasma irradiation at different pressure on seeds

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Atmospheric or low-pressure plasma is a new technology to enhance seed treatment and physicochemical properties of plant. Among legumes, Mung bean (*Vigna radiata*) is an important economic crop which is a good source of protein, vitamin, antioxidant, fat, minerals, etc. Several studies have investigated plasma activated water (PAW)-induced improvements to germination, plant growth, sterilization and enzymatic activity of mung bean. In another study, Antioxidant activity and growth regulation induced by oxygen plasma on seed was investigated on *Raphanus sativus* (radish) sprout [1]. But no information was found on physicochemical properties induced by direct plasma treatment on seed of mung bean at different gas pressure with different exposure time of plasma irradiation. Purpose of this study is to treat the mung bean seed with oxygen plasma at different gas pressure and exposure time to clarify changes in physicochemical properties of mung bean.

Oxygen plasma is generated by low-pressure RF discharge with frequency of 13.56MHz. Mung bean (*Vigna radiata*) seeds (25 seeds in each treatment) were used. Seeds were irradiated with oxygen plasma at pressure of 10, 20, 40, 60, 80, and 100 Pa and exposure time of 10, 30 and 60 min. After 5 days of cultivation period, germination rate, growth performance (stem and root length and weight), Vitamin-C content and antioxidant activity were measured.

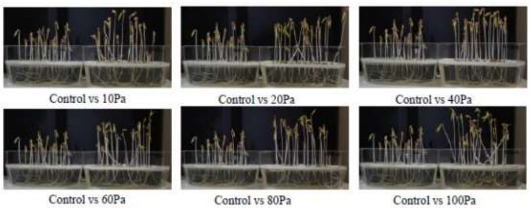

Fig.1. Growth enhancement by plasma treatment at different pressure compared to Control

Seed germination was significantly enhanced after oxygen plasma treatment. After 12 hours of sowing, germination rate increased from 23% to 64% from the control (no plasma) under different gas pressure conditions. Also, plasma treatment enhance growth (stem length, root length, and weight) of Mung bean significantly. Stem and root length increased from 7% to 35% and 7% to 27% higher respectively, compared to the control depending on exposure time and gas pressure (Fig.1). The content of vitamin C in seed, stem, and root varied abruptly at different plasma exposure times with changing pressure (Fig.2). At 60Pa pressure vitamin C content was observed highest (29.75% higher than control). Plasma treatment also showed a remarkable change in antioxidant activity compared to the control.

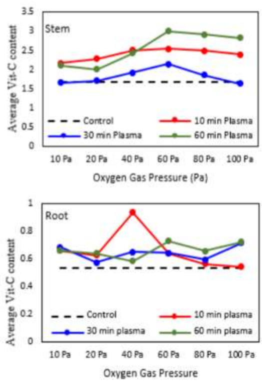

Fig.2. Plasma Treatment Enhanced Vitamin-C Content

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P-26

The possibilities of using cold atmospheric pressure plasma in agriculture - comparison of laboratory-scale plasma source and its modified version for industrial use

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Cold atmospheric pressure plasma (CAP) treatment of seeds for use in agriculture has recently become the subject of significant research efforts. The advantage of CAP is its low-temperature character, which enables the processing of heat-sensitive biological material, minimizes the use of chemicals, and does not require vacuum equipment but uses ambient air as the working gas. Over the past two decades, a lot of scientific knowledge has been obtained declaring the positive effect of CAP plasma on various types of seeds. Plasma treatment has been shown to be an effective decontamination method capable of reducing pathogenic organisms on the surface of seeds. Additionally, many studies have confirmed the positive effect of plasma on seed germination properties and subsequent plant growth. There are also studies that verify other benefits obtained after plasma treatment, such as better resistance of seeds and sprouts to adverse climatic conditions, drought, and the content of heavy metals in the soil [1-3].
For the successful application of plasma technologies directly in companies involved in the production of seeds, it is necessary to develop equipment capable of treating larger amounts of seeds in a continuous production line. In our study, we compared the plasma treatment of seeds using the so-called diffuse coplanar surface barrier discharge (DCSBD) in standard laboratory configuration and a prototype with 2 DCSBD-plasma panels, which can treat larger quantities of seeds at once. The high power density of the plasma is advantageous for more efficient processing with treatment times reduced to seconds. Plasma-induced surface changes were studied by surface diagnostic methods, such as contact angle measurement to determine wettability, and ATR-FTIR, to determine possible changes in chemical composition and bonds on the surface. Physiological changes of plasma-treated seeds, such as germination and growth dynamic parameters (length of roots and shoots, their fresh and dry weight, germination vitality indices) were also monitored in detail. Both plasma configurations have shown to be comparably effective in improving growth parameters. In addition, we observed that if the natural germination of the used seeds was high, the influence of the plasma manifested in increasing the growth parameters of the seedlings.

This work was supported by the Slovak Research and Development Agency under the Contract no. APVV-21-0147.

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P-27

Activation of macrophage-T cell immune system using atmospheric pressure oxygen plasma

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Macrophages play an important role in immune function. They take in pathogens that invade the body and present their antigenic information to T cells. Macrophages are activated by LPS and IFN-γ, which are mainly produced by T cells [1][2]. In previous studies, it was confirmed that macrophages were treated with LPS reagents to increase phagocytosis by 49%. In actual situation in lymph, other immune cells are also irradiated with plasma at the same time as macrophages. In this study, immune activity of macrophage-T cell immune system is investigated using atmospheric pressure oxygen plasma.

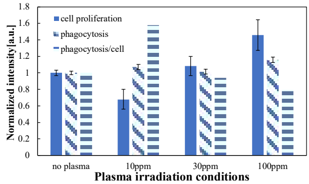

Fig.1 Effects of plasma irradiation of macrophages and T cells on the cell proliferation capacity and phagocytosis of macrophages

Experimental device is consisted of a ceramic tube 100 mm long, 4 mm outer diameter, and 3 mm inner diameter, into which a stainless-steel mesh was inserted as the discharge electrode, and copper tape was wrapped around the outside. Oxygen gas flowed into the plasma source at 0.4 slm, AC high voltage was applied, and plasma irradiation was performed. The applied voltage was set so that the ozone concentration was 10, 30, 100 ppm at the gas outlets. The plasma irradiation time was 30 and 40 sec. After seeding the cells, it was cultured in an incubator. After irradiating macrophages and T cells with plasma, only the supernatant of T cells was added to macrophages. Immediately after that, fluorescent beads were added to measure the phagocytosis of macrophages. 24 hours after adding the supernatant of T cells, the cell proliferation and phagocytosis of macrophages were measured using a microplate reader.

Cell proliferation and enhancement of phagocytosis are investigated by irradiating plasma and adding the supernatant of T cells. Fig. 1 shows the results of cell proliferation and phagocytosis when macrophages and T cells were irradiated under conditions of ozone concentration of 10 ppm, 40 sec, 30 ppm, 30 sec and 100 ppm, 30 sec. At 10 ppm, cell proliferation capacity decreased by 32% compared to no-irradiation, phagocytosis per cell increased by 58%. IFN-γ produced by plasma-irradiated T cells is considered to promote improved phagocytosis. At 30 ppm and 100 ppm, cell proliferation capacity increased and phagocytosis per cell decreased.

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P-28

Cytokine release characteristics of T cells after plasma irradiation in liquid using a porous membrane plasma generator

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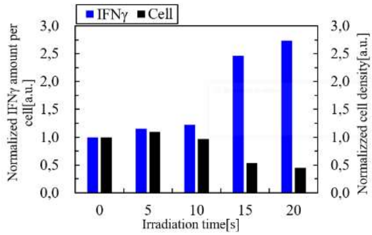

Fig. 1 IFN-γ production amount changing plasma irradiation time.

Recently, it has been shown that plasma irradiation of cells promotes cell proliferation [1]. However, the short-lived reactive species that effectively affect cells are inactivated rapidly in gas and liquid phase and have not contribute to the cell proliferation [2]. In this study, activation of the proliferative capacity of T cells in the culture medium is performed by a porous atmospheric pressure plasma source to shorten the immune cell culture period in immunotherapy. T cell proliferation is achieved by supplying active species directly into the liquid using a porous membrane for gas-liquid separation.

A non-equilibrium atmospheric pressure plasma apparatus was consisted in which a barrier discharge electrode was covered with a porous membrane, and the discharge electrode did not come into direct contact with the liquid even in the liquid. The porous membrane has both water repellency and air permeability, enabling gas-liquid separation. Active species generated by the plasma dissolve into the liquid phase from the gas-liquid interface in the microholes on the porous membrane. Therefore, short-lived reactive species in the plasma are rapidly introduced into the liquid. In this study, mouse CD4+ T cells, EL-4, were irradiated with plasma using a porous atmospheric pressure plasma source to investigate the effects on the cell number density and cytokine release of T cells. Cell suspensions adjusted to an initial cell number density of 2.0×10^5 cells/mL were seeded in 48-well plates of 500 µl each. Plasma irradiation was performed by varying the plasma irradiation time. The distance from the plasma source to the surface of the cell suspension was 0.5 mm, and the source gas was air. After irradiation, cells were incubated for 24 hours, and the cell number density was measured by a cell counter.

The number density of cells was increased up to 1.5 times by plasma irradiation of EL-4 using the porous atmospheric pressure plasma source with air introduced. As the plasma irradiation time increased, the amount of IFN-γ released increased, reaching 2.7 times that of the untreated cells after 20 s of irradiation. The IFN-γ release increased as the cell number density decreased. On the other hand, the amount of IL-4 release decreased significantly regardless of the plasma irradiation time and cell number density, with a 0.02-fold decrease after 5 seconds of the irradiation. These results suggest that plasma irradiation using the irradiation device in this study may induce the Th1 differentiation.

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P-29

Plasma treatment of freshly squeezed carrot juice

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Driven by growing consumer interest in acquiring food with various bioactive ingredients, an impact of low-temperature plasma on the qualitative characteristics of freshly squeezed carrot juice (Nerac variety) was investigated. An experimental set-up consisted of glide-arc reactor operating with air [1]. Microbiological, physicochemical, and structural changes of the product samples after different exposure times to plasma treatment (10, 20, 30 min.) were analysed. The properties of the juices were assessed after 1, 2, and 3 days of storage in the refrigerator at a temperature of 6°C.

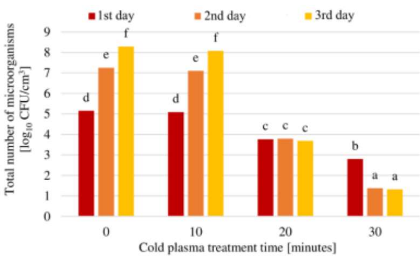

Fig.1. The effect of cold plasma exposure time on the content of total number of microorganisms (n = 4)

Plasma treatment improved microbiological quality of juice compared to the control sample (Fig.1). However, a product compliant with the requirements outlined in the Codex Standards regarding the total aerobic mesophilic microorganism count in edible juice required relatively long treatment time (20 and 30 min). Plasma processing resulted in better colloidal stability and higher content of carotenoids and polyphenols than in the control sample.

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P-30

Induction of differentiation and Cytokine release of EL4 T-cell by Barrier Discharge Oxygen Plasma

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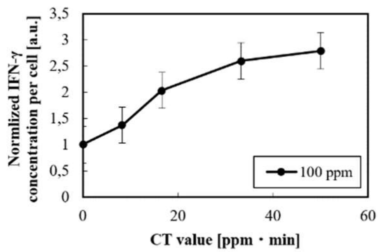

Fig.1 IFN-γ release amount per one cell after O_2 plasma irradiation. Indicator of Th1.

T cells play a central role in cellular immunity because they release cytokines, which are intracellular signal transduction molecules, and regulate the activity of other immune cells. Naïve CD4+ T-cells differentiate into Th1 or Th2 cells when being stimulated by antigen-presenting cells. In our bodies, the cytokines IFN-γ and IL-4 released by Th1 and Th2 cells respectively, interact and maintain a balance of the immune function. Allergic diseased, which have been on the increase in recent years, are thought to be caused in part by an imbalance in the immune system due to the predominance of Th2 cells. Immunosuppressive drugs (e.g., steroids) have been used as existing treatment methods, but they have the problem of suppressing the activity of not only Th2 cells but also other immune cells. From previous experimental results, atmospheric pressure oxygen plasma irradiation into T cells can cause differentiation into Th1 cells due to an increase in the release of the cytokine IFN-γ, or into Th2 cells due to a marked increase in the production of the cytokine IL-4[1)]. From those results, there is a possibility that oxygen plasma irradiation can adjust the Th1/Th2 ratio and treat allergic diseases by activating Th1 cells rather than suppressing Th2 cells. However, the detailed induction factors and characteristics of differentiation by oxygen plasma irradiation are still unknown. The purpose of this study is to clarify the plasma conditions to induce the differentiation of T cells into Th1 or Th2 cells.

The torch-type plasma source generated by dielectric barrier discharge was used. Oxygen gas was flowed into the tube at 0.6 L/min and generated the plasma with the gaseous ozone concentration at 30, 70, 100 ppm. The cell suspension was diluted to an initial cell density of 2.5×10^5 cells/mL and dispense 100 μl of cell suspension per one well in 96-well plates. The plasma irradiated the surface of the culture medium. After irradiation, the production of IFN-γ and IL-4, cytokines released by Th1 and Th2 cells respectively, were measured by ELISA method. Figure 1 shows the amount of cytokine IFN-γ per one cell after 24 hours from the plasma irradiation to confirm the differentiation characteristics to Th1 cell. According to this graph, as the CT value increased, the amount of cytokine IFN-γ also increased in the range of CT values from 0 to 50. On the other hand, there was no association between the release amount of cytokine IL-4 and CT values in the lower range of CT values (0 ~ 50). However, when CT values were 100 ~ 300, the release amount of cytokine IL-4 increased significantly with increasing CT values. Therefore, there is possibility to be able to regulate differentiation into Th1 or Th2 changing the ozone concentration that indicates amount of active oxygen species dissolved in the culture medium.

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P-31

Improved working gas utilization by Gliding Arc Discharge with twisted electrodes

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Over the past decade, the application of atmospheric pressure plasma has progressed rapidly. In particular, progress in the agricultural fields has been remarkable. The advantage of atmospheric pressure plasma is that it does not require a vacuum system. However, it is not easy to maintain a stable discharge in an atmospheric pressure environment. So far, we have focused on gliding arc discharge (GAD). In our previous research, we have proposed UV irradiation of electrodes as a method of lowering the discharge start voltage in GAD.[1] This method improves the controllability of total power. However, there are many problems with 'classical GAD'. The first problem is that GAD is an un-steady discharge. During the time of extinction, the working gas passes through the electrodes without any effect on the gas. Also, only the area where the current path exists between the electrodes is in plasma, while the gas passes through most of the rest of the space at almost room temperature. Because of these characteristics, the most basic single-phase GAD is not suitable for use in processes that break down working gases. Therefore, we have developed 6 & 12 phase, 6 &12 electrodes GADs, but the power supply configuration has become complicated.[1] Another proposal is the tornado type GAD. This is an excellent equipment configuration and has quickly expanded the range of GAD applications. However, although the tornado type GAD is efficient for producing plasma from the working gas, it is more difficult to use than classical GAD for applications where GAD plasma is irradiated to something. In this study, a single-phase twisted-electrode GAD was proposed to improve the processability of the GAD for seed processing. The twisted electrode rotated the discharge path in the space of the discharge tube. Furthermore, the gas introduction path was divided into two parts: the shortest part of the electrode in the axial direction and the radial direction to ensure the stability of the discharge.

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P-32

Electrodynamic flow induced in a liquid by a dual frequency APPJ

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Atmospheric pressure plasma jets have been widely studied due to their ability to trigger chemical reactions and polymerization. When used in contact with liquid surfaces they are able to induce electrons solvation and the production of hydroxyl radical and reactive oxygen and nitrogen species. However, the interaction with the fluid generates electro-induced currents [1], which depend on time and on the mobility of the ions in the solution. Particle Image Velocimetry on the liquid flow had allowed to highlight the fluid motion in contact with different sources from the nanopulse or RF up to the streamer discharges [2]. This flow is then linked also to the process's efficiency of nanoparticle production up to water remediation.

The dual frequency HF (17 kHz) + RF (27 MHz) atmospheric pressure plasma jet configuration accounts for an innovative interaction with the surfaces coupling an RF plasma with the substrate. In this configuration the ions flow to the fluid through the whole HF cycle, with an enhancement controlled by the HF voltage. At the same time an RF current of tens of milliampere passes continuously through the liquid.

To assess how this dual frequency generation affects the jet interaction with the fluid, we propose to perform a preliminary Particle Image Velocimetry analysis using blue poly-ethylene microspheres with a diameter ranging from 53 µm to 73 µm. We will investigate the effects of argon flow, liquid conductivity and electro-induced current on the motion of particles within the liquid solution. The information recorded as a function of time will be linked to pH and conductivity measurements in order to highlight the limits of a stable condition treatment.

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P-33

Removal of lead from water by Non-thermal Oxygen Plasma treatment

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Water scarcity and water pollution are major issues in the world at present. Heavy metals like arsenic, copper, cadmium, chromium, nickel, zinc, lead, and mercury are major pollutants in freshwater reservoirs because of their toxic, non-biodegradable, and persistent nature. Chronic exposure to heavy metals and metalloids can damage various organs like kidneys, liver, lungs, brain, and bones [1]. Recently, plasma technology has been tested for the cleaning of polluted water. But most of the research on plasma application is focused on the disinfection and removal of organic wastes from wastewater. Oxidation of the heavy metal ions sometimes produces deposits of metal oxide after oxidation of the heavy metal ions [2]. These metal oxide deposits can be removed from the water easily. This study attempts to remove lead (Pb) ions from water using the non-thermal oxygen plasma method.

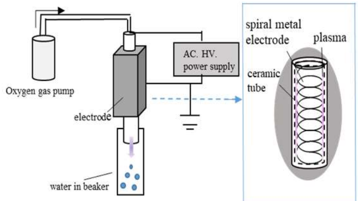

Fig. 1. Schematic diagram of experimental apparatus.

The ozone oxidation of the dissolved lead ion is performed by the simple ozone bubbling in the water containing the ions. The amount of water is 0.2 L and there is no water flow in the water vessel. The ozone is generated by the torch shape dielectric barrier discharge (DBD) plasma using pure oxygen gas with a flow rate of 1.0 L/min and the discharge voltage is approximately 5 kV (Fig. 1). Effect of the oxidation of the lead is evaluated by the generation amount of lead oxide that deposits on the bottom of the vessel. The deposit is extracted from the water and dried up. The weight of the dried deposit is measured using the precision measure.

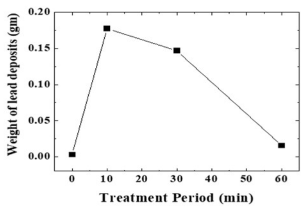

Fig. 2. Weight of lead oxide deposit at different treatment period.

When the lead ion dissolved water contacts with ozone, light yellow to dark red color deposits of oxides of lead are produced with the increasing treatment period. Weight of the lead ion deposit increases initially up to 10 min, and then decreases with the irradiation period (Fig. 2). When the treatment period increases longer than 10 min and ozone is kept injected in the water then light red color lead monoxide (PbO) deposit changes to dark red color lead oxide (Pb_3O_4) deposit. The maximum amount of lead oxide deposit from water is achieved at the treatment period of 10 min.

[1] P. B. Tchounwou, C. G. Yedjou, A. K. Patlolla, and D. J. Sutton, in *Molecular, Clinical and Environmental Toxicology*, Vol. 101, 133-164 (2012).

[2] F. Fu and Q. Wang, *J. Environ. Manage.*, 92(3), 407-418 (2011).

P-34

Effect of plasma gas parameters on the efficiency of a three-phase plasma reactor with gliding arc discharge

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Three-phase gliding arc discharge reactors are devices in which it is difficult to maintain stable plasma parameters, both electrically, physically and chemically [1]. Plasma instabilities translate into the electrical efficiency of the plasma reactor. As a result of the low efficiency, the plasma reactor takes an amount of energy from the power grid that is greater than that required for plasma processes. This translates into high reactor operating costs and thus high plasma process costs. From the analysis carried out for the three plasma-generating gases: nitrogen, argon and helium, it is clear that the chemical composition of the gas and its physical parameters have a major impact on the quality of the generated plasma and thus on the efficiency of the plasma reactor. As a measure of the quality of the generated plasma, one can take the frequency of voltage collapse, overvoltage, noise, the content of h igher harmonics in voltage and current, and the level of electromagnetic interference generated by the arc. The main cause of plasma instability is its source, which is freely burning arcs in a three-phase system. In addition, these arcs burn at low currents and are intensively cooled, which further increases their instability. It should be borne in mind that the design of the power supply itself affects the discharge parameters and therefore the efficiency of the plasma reactor [2]. Depending on whether one has a converter or transformer power supply, one obtains, with the same electrical parameters at their outputs and the same process gas parameters, different plasma generation efficiencies. In the case of transformer power supplies, even the material of the cores has an influence. The plasma reactor together with the power supply system, the process gas supply system and the regulation and control system are an integral part of the plasma generation system. In order to achieve the required plasma parameters while maintaining good plasma reactor efficiency, the plasma generation system should be considered as a whole.

[1] N. Pourali *et al*., "*Study of plasma parameters and gas heating in the voltage range of nondischarge to full-discharge in a methane-fed dielectric barrier discharge*", Plasma processes and polymers, Vol. 20, Issue 1, January, (2023).

[2] G. Komarzyniec, H. D. Stryczewska, P. Krupski, "*The Influence of the Architecture of the Power System on the Operational Parameters of the Glidarc Plasma Reactor*", In *IEEE Pulsed Power & Plasma Science (PPPS)*, Orlando, FL, USA, (2020).

P-35

New linear plasma jet system based on Diffuse Coplanar Surface Barrier Discharge

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Atmospheric plasma sources are important tools for a wide range of applications in modern surface processing technologies. Cost-effective, fast-throughput and scalable plasma technologies working at atmospheric pressure are preferred by the industry. Diffuse Coplanar Surface Barrier Discharge (DCSBD) is well known as a source of high-power density plasma suitable for large-area plasma surface processing of various flat and flexible materials.

Since the DCSBD generates atmospheric plasma as a thin (~ 0.3 mm) uniform layer of high-power density (100 W.cm^{-3}) plasma in all technically important gases, it is highly suitable and effective for direct plasma surface modification of flat sheets and flexible materials like foils/textiles/paper. On the other hand, such direct plasma treatment requiring very close "contact" of the DCSBD plasma unit with the modified material is ot suitable for plasma surface processing of structured and complex 3D surfaces.

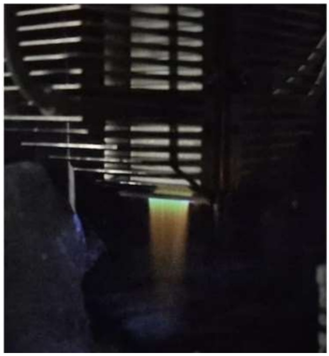

Figure 2: Nitrogen plasma generated by linear jet in open air configuration.

Therefore, we designed a new plasma source based on robust DCSBD technology that possesses all the advantages of DCSBD design like robustness, virtually unlimited lifetime of the electrode system and generation of low-temperature plasma. We will present the operational parameters of the linear plasma jet system (Figure 1) based on DCSBD technology and show the discharge characteristics generated in air and nitrogen in open air and also in closed chamber configuration. We will compare the new plasma source and the conventional surface DCSBD plasma as well as similar commercial plasma systems generating remote atmospheric plasmas. Finally, we will give examples of the results of the plasma modification of selected materials using this new plasma system.

P-36

Center tapped transformer for Glidarc plasma technique

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Plasma generated by discharge sliding under atmospheric pressure has a high application potential. Innovative applications of this type of plasma include: precipitation deposition method to generate fibrous catalysts. These catalysts are used in the reactions of soot combustion and CO oxidation [1]. What is exceptionally modern, there are reports of the use of plasma from a sliding discharge to activate biofibers used for the production of bio composites [2]. The use of glidarc afterglow also seems to be a very promising option. It is known that the generation of glidarc plasma is associated with an electric discharge in the process gas between the arcuate electrodes. The glidarc reactor is therefore a receiver with particularly non-linear characteristics. A sliding discharge plasma reactor power supply system based on a pulse inverter source was designed. In the power supply system, an unusual transformer is responsible for adjusting the voltage level. The primary side is represented by a coil with a center tap. Of course, due to operation at frequencies 10 - 30 kHz, a copper litz wire winding was used. The secondary side is also unusual. Not one, but chain of divided secondary windings are used here in a split carcass system. The transformer power is foreseen at 1 kW RMS. The design provides for a power overload up to 3 kW RMS for the inverter-transformer set. Interestingly, the voltage needed to ignite the discharge does not result from the winding turn ratio and the primary side voltage. A set of parasitic phenomena in the primary side circuit is used, including; strong impact of primary leakage inductance and the so-called elements vertical branch of the equivalent diagram.

[1] M. Rodriguez, S. A. Leonardi, F. Hanon, E. E. Miró, V. G. Milt, and E. M. Gaigneaux, "Plasma-assisted deposition of Mn and Fe phases on CeO2 biomorphic fibers for soot combustion and CO oxidation," *Catalysis Today*, vol. 431, p. 114457, Apr. 2024, doi: 10.1016/j.cattod.2023.114457.

[2] G. Dionmbete *et al.*, "Hybrid composite with lignocellulosic biomass supported titania obtained under plasma conditions for photocatalytic application," *Biomass Conv. Bioref.*, May 2023, doi: 10.1007/s13399-023-04246-1.

P-37

Exploring the influence of experimental method and apparatus on energy measurement in Partial Discharge or Monofilament DBD at atmospheric pressure in air

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Partial discharge (PD) is a localized electrical breakdown that can occur in the gas or solid electrical insulation. As electrical system voltages rise, PDs are becoming increasingly important to study. PDs are similar to the microdischarges observed in a Dielectric Barrier Discharge (DBD) configuration. However, unlike a DBD, PDs can lead to erosion of the polymer insulating material, which can ultimately cause arcing and a system failure.
Due to the small ionization level and the relatively small size of PDs, the measurement of their energy is a very challenging task. Several studies have been conducted to investigate the measurement of microdischarge energy using Lissajous figures [1,2] or current measurement, with a capacitance or resistance in series with the discharge. In this study, we will use these methods to measure the very low energy of a PD (4 µJ by periods) obtained in a configuration with a spherical high voltage electrode (radius=2mm) and a planar ground electrode separated by a polymer dielectric (thickness=125 µm) as presented in Figure 1. We will compare the results obtained with these two methods and examine the influence of the acquisition system (acquisition frequency, oscilloscope sampling rate, and vertical resolution) on the value of the measured energy. After a signal processing, we are able to measure an energy lower than 10 µJ on a voltage cycle. This work will be helpful for the electrical characterization of both microdischarges and partial discharges.

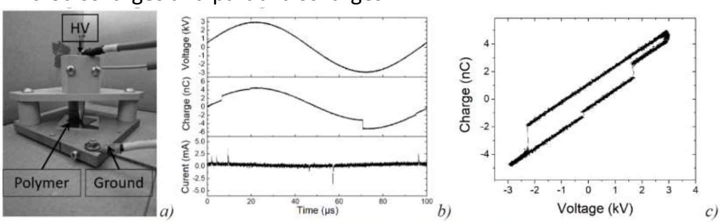

Figure 1 : Example of measurements for a DP in air at atmospheric pressure (3kV, 10kHz): a) Experimental setup; b) temporal evolution of applied voltage, current and charge; c) Associated Lissajous figure

Figure 1: Example of measurements for a DP in air at atmospheric pressure (3kV, 10 kHz): a) Experimental setup; b) temporal evolution of applied voltage, current and charge; c) Associated Lissajous figure

[1] T. C. Manley, Trans. Electrochem. Soc. **84**, 83 (1943).
[2] A. V. Pipa *et al.*, Review of Scientific Instruments **83**, 075111 (2012).

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