# P 7: Atmospheric Pressure Plasmas and their Applications III

Time: Tuesday 17:00–19:00 Location: CHE/0089

P 7.1 Tue 17:00 CHE/0089

**Operation modes of the COST plasma jet** — •Maximilian Klich, David Schulenberg, Máté Vass, Katharina Nösges, Sebastian Wilczek, and Ralf P Brinkmann — Ruhr University Bochum, 44780 Bochum, Germany

Discharges ignited at ambient pressure drive complex chemistry. This chemical variety offers plenty of applications; for example, wound healing. A commonly used plasma source at atmospheric pressures is the COST plasma jet, a capacitively coupled radio-frequency driven plasma jet. The main goal of this study is to demonstrate three distinct operation regimes of the COST jet and to indicate their relation. The work is conducted by applying a hybrid particle-in-cell/Monte Carlo collisions (PIC/MCC) simulation code between the jet's electrodes (i.e., a one-dim. setup) for He/N2 chemistry. The framework treats electrons kinetically via PIC/MCC and solves the continuity equation based on the drift-diffusion approximation for all ion species. We vary basic input parameters (e.g., the driving frequency or voltage) to control the discharge regimes. It shows that the scaling of the Debye length, the average sheath width, and the discharge length are comparable in magnitude. Depending on their exact values, the discharge enters one of three modes: (i) A quasi-neutral regime where distinguishable bulk and sheath areas exist. (ii) A non-neutral regime where no quasi-neutral bulk region is developed. (iii) All dynamics are constricted to tiny sheath regions shielding a vast, steady bulk region in the constricted mode. Overall, this work offers parameters for distinct operation modes that allow tailoring the discharge.

P 7.2 Tue 17:15 CHE/0089

**A comparison of the spatial distribution of $H_2O_2$ in the effluent of the kINPen-Sci and the COST Reference Microplasma Jet** — •Levin Krös[1], Ben Harris[2], Andy Nave[1], Erik Wagenaars[2], and Jean-Pierre van Helden[1] — [1]Leibniz Institute for Plasma Science and Technology (INP), Greifswald, Germany — [2]York Plasma Institute, Department of Physics, University of York, UK

Cold atmospheric plasma jets (CAPJs) are utilised in biomedical applications, as they provide important reactive oxygen and nitrogen species (RONS) for the plasma cell interaction, such as $H_2O_2$. There are still open questions in the physical and chemical field regarding the production of the RONS. Where are they formed and how does the jet-type has an influence on their production? As a first step to resolve that question, the production of $H_2O_2$ in humidified helium is compared between the kINPen-Sci and the COST Reference Microplasma Jet. The small sample length (about 4 mm) combined with low number densities are a challenge for established absorption spectroscopic techniques. Continuous-wave cavity ring-down spectroscopy (cw-CRDS) is applied in order to increase the path length through the sample. The difference in the spatial distribution of $H_2O_2$ in the effluent between the jets will be discussed.

P 7.3 Tue 17:30 CHE/0089

**Gas temperature variations along the discharge channel in an atmospheric pressure RF plasma jet and their consequences on electron dynamics** — •David A. Schulenberg[1], Maximilian Klich[1], Zoltán Donkó[2], Máté Vass[1,2], Jeldrik Klotz[1], Nikita Bibinov[1], Julian Schulze[1], and Thomas Mussenbrock[1] — [1]Ruhr University Bochum, German — [2]Wigner Research Center for Physics, Budapest, Hungary

The gas temperature increase along the discharge channel of a radio frequency micro-atmospheric pressure plasma jet is investigated by a combination of spectroscopic measurements and particle in cell (PIC) simulations. The jet is operated using Helium-Nitrogen mixtures of He:N2 ratios of 1000:0.5 to 1000:2. We find that under standard operating conditions, the increase in gas temperature depends on the nitrogen content of the jet gas, the driving voltage, and the driving voltage waveform. Depending on the exact combination of these parameters, the gas temperature increases approximately 80 K between the gas inlet and the nozzle of the jet. Phase Resolved Optical Emission Spectroscopy measurements reveal a change of the time- and space-dependent dynamics of the high energy electrons in the plasma under operating conditions at which the gas temperature determined by optical emission spectroscopy also changes. This behavior is reproduced by PIC simulations, in which the gas temperature is an input parameter. The dependence of the operation mode on the gas temperature might offer an additional degree of freedom in terms of controlling the plasma properties in order to match specific application requirements.

P 7.4 Tue 17:45 CHE/0089

**Modeling and simulation of transport processes in capacitively coupled radio-frequency-driven micro atmospheric pressure plasma jets** — •Lukas L. Vogelhuber, Katharina Nösges, Maximilian Klich, Thomas Mussenbrock, and Ralf Peter Brinkmann — Faculty of Electrical Engineering and Information Technology, Ruhr University Bochum, Bochum, Germany

Capacitively coupled radio-frequency-driven micro atmospheric pressure plasma jets (CCRF $\mu$APPJ) are used in biomedical science and $CO_2$ conversion. Numerical methods offer a range of possibilities to investigate a $\mu$APPJ's gas and plasma dynamics. A hybrid simulation code is implemented to investigate a CCRF $\mu$APPJ that handles electrons kinetically in a particle-in-cell/Monte Carlo collisions (PIC/MCC) scheme and ions and other heavy particles in a fluid mechanical manner. The simulation cycle of charged and neutral particles is separated, accounting for their different time scales and to spare computational resources. A one-dimensional continuity equation for the charged heavy particles is solved based on the drift-diffusion approximation. For neutral heavy particles, the gas flow is modeled by Hagen Poisseuille's law, and a two-dimensional continuity equation is solved. The main goal of this work is implementing a scheme that can solve complex chemistry and gas transport and gives two-dimensional (2D) resolved data without evoking a full 2D-PIC scheme. With the exemplary chemistry of $He/N_2$ this work shows that the presented scheme is suitable for the communication between separate plasma and gas dynamics simulation that creates a multi-physics framework.

P 7.5 Tue 18:00 CHE/0089

**Impact of feed gas humidity on the discharge dynamics in an Ar-operating atmospheric pressure plasma jet** — •Sarah-Johanna Klose, Robert Bansemer, Ronny Brandenburg, and Jean-Pierre H. van Helden — Leibniz-Institut für Plasmaforschung und Technologie e.V. (INP), Greifswald, Deutschland

Cold atmospheric pressure plasma jets are often employed for biomedical purposes as they provide a large variety of reactive species remaining around room temperature, such as atomic and molecular radicals, and key species, such as $H_2O_2$. In particular, hydrogen, oxygen and nitrogen containing species have been proven beneficial for wound healing and cancer treatment. The formation of these species starts in general with the dissociation of molecular gases in the plasma zone of the plasma jet. It has been shown previously that by the addition of water to the feed gas, the composition of reactive species could be changed drastically. In this presentation, we will demonstrate the impact of feed gas humidity on the discharge dynamics of the kINPen-sci plasmajet, a cold atmospheric pressure plasma jet that is operating with Ar. By means of time-resolved laser atomic absorption spectroscopy (LAAS), absolute densities of $Ar(^3P_2)$ species have been determined as a function of the feed gas humidity and of the distance to the nozzle of the plasmajet. By analysing the quenching, conclusions on the dissociation of water have been drawn, which will also be presented.

P 7.6 Tue 18:15 CHE/0089

**Impact of humidity on the OH distribution in the effluent of an atmospheric pressure plasma jet measured by laser induced fluorescence** — •Judith Golda[1], Sebastian Burhenn[1], Maike Kai[1], Pia-Victoria Pottkämper[1], Volker Schulz-von der Gathen[2], and Marc Böke[2] — [1]Plasma Interface Physics, 44801 Bochum, Germany — [2]Experimental Physics II, Ruhr University Bochum, 44801 Bochum, Germany

For plasma sources operating in ambient atmosphere, such as the COST-Jet, the environmental conditions have a sensitive impact on the reactive species leaving the discharge zone. One important parameter is humidity: Water impurities in the feed gas or diffusion of moisture from the ambient atmosphere in the gas stream can contribute to an increase of humidity in the effluent. To study these effects, OH as a side-product from the dissociation of water by the plasma can be used as a tracer molecule. Therefore, we measured the 2D-distribution

of OH produced in the COST-Jet by laser induced fluorescence. To control the influence of gas composition and humidity of the ambient atmosphere, the experiments were performed inside a closed vessel. By systematically varying the water content of the gas inside the vessel by a bubbler system, the influence of humidity on the OH density profile was studied. These results were then compared to profiles, which were obtained from the variation of humidity in the feed gas providing valuable information about the production channels of OH.

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P 7.7 Tue 18:30 CHE/0089

**Photo-chemistry of organosilicon precursors initiated by VUV/UV-radiation from an atmospheric pressure RF plasma jet** — •Tristan Winzer, Natascha Blosczyk, and Jan Benedikt — Institute of Experimental and Applied Physics, Kiel University, Kiel, Germany

Thin-film deposition using plasmas at atmospheric pressure is a topic of current research, because sources and setups are more simple and cost-effective when compared to their low-pressure counterparts. Furthermore, they enable continuous treatment of vacuum-sensitive substrates.

However, direct contact of the precursor with the plasma can lead to unwanted particle formation and ambient conditions influence the film via impurities from nitrogen, oxygen and water. To overcome these limitations, we use high purity noble gas in a setup that provides effective separation of plasma species and precursor gas and utilizes the VUV/UV-radiaton from the plasma to initiate photo-chemistry. Photo-chemistry products of different organosilicon precursors in dependence of plasma power and precursor gas flow will be analyzed using ion mass spectrometry with the goal of optimizing conditions for effective film deposition. Deposited films are analyzed using Fourier-transform infrared spectroscopy (FTIR).

P 7.8 Tue 18:45 CHE/0089

**Anomalous $N_2^+(B^2\Sigma_u^+)$ population in the discharge and the afterglow of an APPJ in $N_2$** — •Nikita Lepikhin[1], Nikolay Popov[2], Dirk Luggenhölscher[1], Nader Sadeghi[3], and Uwe Czarnetzki[1] — [1]Institute for Plasma and Atomic Physics, Ruhr University Bochum, Bochum, Germany — [2]Moscow, Russia — [3]Laboratoire Interdisciplinaire de Physique, LIPhy, CNRS, UMR 5588, Laboratoire des Technologies de la Microélectronique, LTM, CNRS, UMR 5129, Université de Grenoble-Alpes, Grenoble, France

An anomalously high relative density of the $N_2^+(B^2\Sigma_u^+, v = 0)$ state is observed in the plasma bulk of a nanosecond near-atmospheric pressure plasma jet in nitrogen during its quasi-DC phase and afterglow. Additional population of $N_2^+(B^2\Sigma_u^+, v = 0)$ is confirmed by analyzing the rotational structure of the (0-0) transition of the First Negative System (FNS) of nitrogen. Numerical kinetic modeling is used to identify possible mechanisms of additional $N_2^+(B^2\Sigma_u^+, v = 0)$ formation. Kinetic calculations taking into account production of $N_2^+(B^2\Sigma_u^+, v = 0)$ in reaction between the $N_2(a^1\Pi_g)$ and $N_2(C^3\Pi_u)$ states as well as in reaction of the $N_2(a^1\Pi_g)$ state with the $N_4^+$ ion describe adequately the FNS(0-0) emission dynamics and the high relative density of the $N_2^+(B^2\Sigma_u^+, v = 0)$ state observed experimentally.