5th Asia-Pacific Conference on Plasma Physics, 26 Sept-1Oct, 2021, Remote e-conference

Diagnostic and application of Cold Atmospheric Plasmas as sources of reactive species

Jan Benedikt[1], Tristan Winzer[1], Christian Schulze[1], Kerstin Sgonina[1], Judith Golda[2]
[1]Institute of Experimental and Applied Physics, Kiel University, Germany
[2]Plasma Interface Physics, Ruhr-University Bochum, Germany
e-mail (speaker): benedikt@physik.uni-kiel.de

Cold atmospheric plasmas (CAP) are an effective source of highly reactive species such as O, OH, $O_2(^1\Delta)$, O_3, NO_x and many others. The non-equilibrium character with heavy species (gas) temperature bellow 40°C allows direct plasma contact with liquids or living tissues with novel applications in water remediation, electrolysis or so-called plasma medicine. Molecular beam mass spectrometry (MBMS) for detection of neutral reactive and stable species and positive and negative ions from atmospheric pressure plasmas will be introduced and discussed in detail as a powerful and flexible diagnostic method [1,2]. The advantage of mass spectrometry is that it measures them directly at the surface, the place of interest for any surface treatment, and it is not limited by existence of accessible optical transitions. Additionally, mass spectrometry provides absolute densities of the measured species when properly designed and carefully calibrated. With the application of threshold ionization mass spectrometry (TIMS) it can even provide information about vibrational excitation of the detected species or about electronically excited metastables. The ion mass spectrometry can provide information about the formation of positive and negative ions (and ion clusters) in the effluent and provides supporting information about the influence of variety of species (including impurities) on plasma chemistry. Additionally, the concept of windowless vacuum ultraviolet spectroscopy in the range of 60 to 200 nm will be introduced as a complementary diagnostic of internally excited species in the discharge [3]. These experimental results serve for validation of plasma-chemistry models and rate-equation calculations, which can provide deep insight into the whole plasma and plasma-surface interaction. Cold atmospheric plasma chemistry processes in gas mixtures and at the surface are relevant for gas conversion [4], material processing [5], plasma medicine [6] or plasma agriculture applications including liquid treatments [7,8]. Several examples of investigation of these processes with above mentioned diagnostics will be discussed.

References

[1] J. Benedikt, H. Kersten, A. Piel, *Foundations of measurement of electrons, ions and species fluxes toward surfaces in low-temperature plasmas*, Plasma Sources Sci. Technol. 30 (2021) 033001,

[2] S. Große-Kreul, S. Hübner, S. Schneider, D. Ellerweg, A. von Keudell, Š. Matějčík, J. Benedikt, *Mass spectrometry of atmospheric pressure plasmas*, Plasma Sources Sci. Technol. 24 (2015) 044008,

[3] J. Golda, B. Biskup, V. Layes, T. Winzer, J. Benedikt, *Vacuum ultraviolet spectroscopy of cold atmospheric pressure plasma jets*, Plasma Process. Polym. 17 (2020) e1900216

[4] G. Willems, A. Hecimovic, K. Sgonina, E. Carbone, J. Benedikt, *Mass spectometry of neutrals and positive ions in He/CO_2 non-equilibrium atmospheric plasma jet*, Plasma Phys. Cont. Fusion 62 (2020) 034005

[5] D. Mariotti, T. Belmonte, J. Benedikt, T. Velusamy, G. Jain, V. Švrček, *Low-Temperature Atmospheric Pressure Plasma Processes for "Green" Third Generation Photovoltaics*, Plasma Process. Polym. 13 (2016) 70

[6] S. Bekeschus, K. Wende, M. Mokhtar Hefny, K. Rödder, H. Jablonowski, A. Schmidt, T. von Woedtke, K.-D. Weltmann, J. Benedikt, *Oxygen atoms are critical in rendering THP-1 leukaemia cells susceptible to cold physical plasma-induced apoptosis*, Scientific Reports 7 (2017) 2791

[7] J. Benedikt, M. Mokhtar Hefny, A. Shaw, B. R. Buckley, F. Iza, S. Schäkermann, J. E. Bandow, *The fate of plasma-generated oxygen atoms in aqueous solutions: non-equilibrium atmospheric pressure plasmas as an efficient source of atomic $O_{(aq)}$*, Phys. Chem. Chem. Phys. 20 (2018) 12037, DOI: 10.1039/c8cp00197a

[8] K. Sgonina, G. Bruno, S. Wyprich, K. Wende, J. Benedikt, *Reactions of plasma-generated atomic oxygen at the surface of aqueous phenol solution: Experimental and modeling study*, J. Appl. Phys. 130, (2021) 043303