Development and application of advanced laser-based diagnostics in low and atmospheric pressure plasmas

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Numerous applications of low-temperature plasma physics and technology are part of our daily life and industrial production, not only in the microelectronics industry that forms the technological base of modern society, but also in areas as diverse as nanoscience, photovoltaics, biomedicine and plasma medicine. Despite the ever-growing applications, a common problem to all subfields is that many plasma processes and properties are far from being completely understood, in particular, the physical and chemical interaction of plasmas with solids and liquids. It is therefore essential to diagnose the fluxes of the generated species, to identify the relevant reaction pathways, to be able to tailor the reaction products for specific (biomedical) applications, and to gain further insight into plasma-induced reactivity in condensed matter systems. This requires high precision measurements of reactive molecular precursors, free radicals and short-lived species and their surface reaction steps currently below the achievable detection limits. The typical low abundances of the key transient reactive species, nowadays often in combination with small plasma dimensions, make the detection of these species a challenge. To overcome the limitations of previous studies, novel diagnostics have been developed.

First, I will discuss the application of cavity-enhanced spectroscopy (CES) to determine the concentration of HO$_2$ and its reaction kinetics in atmospheric pressure plasma jets. With CES, effective absorption path lengths of up to 100 meters in mm-sized plasma jets were achieved. Hence, we are able to increase the sensitivity to detection limits of ppb down to ppt levels.

We are currently setting up a novel in-situ experimental approach for space and time-resolved studies of plasma-surface interactions. We use a state-of-the-art mid-infrared frequency comb (FC) to provide novel spectroscopic data on plasma-surface problems. Broadband direct frequency comb spectroscopy (DFCS), based on FCs as the light source, can detect many transient species simultaneously yielding comprehensive data on their kinetics in the plasma and their interactions with a surface down to the microsecond timescale. We demonstrate the capabilities of this advanced laser-based diagnostic by showing the latest results on the spectroscopic investigations of plasma nitrocarburizing processes with mid-infrared DFCS. Our frequency comb operates around 3.2 µm, the fingerprint region for key process species such as NH$_3$, C$_2$H$_2$, C$_2$H$_6$, HCN, and CH$_4$ molecules. We will discuss the workings of DFCS and the influence of process parameters on the concentrations of these species.