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EXCITATION AND IONISATION DYNAMICS IN HIGH-FREQUENCY PLASMAS

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Abstract. Non-thermal low temperature plasmas are widely used for technological applications. Increased demands on plasma technology have resulted in the development of various discharge concepts based on different power coupling mechanisms. Despite this, power dissipation mechanisms in these discharges are not yet fully understood. Of particular interest are low pressure radio-frequency (rf) discharges.

The limited understanding of these discharges is predominantly due to the complexity of the underlying mechanisms and difficult diagnostic access to important parameters. Optical measurements are a powerful diagnostic tool offering high spatial and temporal resolution. Optical emission spectroscopy (OES) provides non-intrusive access, to the physics of the plasma, with comparatively simple experimental requirements. Improved advances in technology and modern diagnostics now allow deeper insight into fundamental mechanisms.

In low pressure rf discharges insight into the electron dynamics within the rf cycle can yield vital information. This requires high temporal resolution on a nano-second time scale. The optical emission from rf discharges exhibits temporal variations within the rf cycle. These variations are particularly strong, in for example capacitively coupled plasmas (CCPs), but also easily observable in inductively coupled plasmas (ICPs), and can be exploited for insight into power dissipation. Interesting kinetic and non-linear coupling effects are revealed in capacitive systems. The electron dynamics exhibits a complex spatio-temporal structure. Excitation and ionisation, and, therefore, plasma sustainment is dominated through directed energetic electrons created through the dynamics of the plasma boundary sheath.

In the relatively simple case of an asymmetric capacitively coupled rf plasma the complexity of the power dissipation is exposed and various mode transitions can be clearly observed and investigated. At higher pressure secondary electrons dominate the excitation and sustainment of the discharge. As the pressure decreases the discharge operates in so-called 'alpha-mode' where the sheath expansion is responsible for discharge sustainment. Decreasing the pressure towards the limit of operation (below 1 Pa) the discharge operates in a regime where kinetic effects dominate plasma sustainment. Wave particle interactions resulting from the flux of highly energetic electrons interacting with thermal bulk electrons give rise to a series of oscillations in the electron excitation phase space at the sheath edge. This instability is responsible for a significant energy deposit in the plasma when so-called 'ohmic heating' is no longer efficient. In addition to this an interesting electron acceleration mechanism occurs during the sheath collapse. The large sheath width, due to low plasma densities at the lower pressure, and electron inertia allows the build up of a local electric field accelerating electrons towards the electrode.

Multi-frequency plasmas, provide additional process control for technological applications, and through investigating the excitation dynamics in such discharges the limitations of functional separation is observed. Non-linear frequency coupling is observed in plasma boundary sheaths governed by two frequencies simultaneously. In an alpha-operated discharge the

sheath edge velocity governs the excitation and ionisation within the plasma, and it will be shown that this is determined by the time varying sheath width. The nature of the coupling effects strongly depends on the ratio of the applied voltages. Under technologically relevant conditions (low frequency voltage $>>$ high frequency voltage) interesting phenomena depending on the phase relation of the voltages are also observed and will be discussed.