Analysis of the electron population in non-equilibrium plasmas sustained by low-frequency, RF, and microwave electric fields

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Résumé

The electron temperature, Te, is one of the most fundamental parameter of non-equilibrium plasmas and is a crucial feature to understand the electron heating dynamics and to control the plasma chemistry in many technological applications. In low-pressure plasmas, Te is usually analyzed by Langmuir probes. However, such measurements are difficult in reactive plasmas due to inherent probe contamination. In addition, analysis of the high-energy electrons are difficult due to their low density and the presence of an ion current that needs to be subtracted from the total measured current. In non-thermal plasmas at atmospheric pressure, Te values have been mostly determined from the neutral bremsstrahlung emission and Thomson scattering. However, such measurements are difficult or even impossible in low-density plasmas, for example, dielectric barrier dicharges (DBDs). In this work, a combination of optical emission spectroscopy (OES) and collisional-radiative modeling (CRM) is used to analyze the electron temperature in various non-equilibrium plasmas sustained by low-frequency, RF, and microwave electromagnetic fields. In low-pressure plasmas, this OES-CRM approach was used to analyze wave-particle interactions and collisionless electron heating in surface-wave argon-based plasma columns. In such microwave plasmas, a resonance can be excited close to the tube walls where the electron plasma frequency in the radially-inhomogeneous plasma column reaches the wave frequency. Through detailed analysis of the 2p-to-1s emission lines from Ar but also Ne, Xe, and Kr injected in trace amounts, the EEDF is found to depart from a Maxwellian with the presence of a high-energy tail. In addition, the relative population of high-energy electrons increases with the axial distance towards the end of the plasma column where the electron density decreases and the resonance point becomes closer to the discharge axis. The OES-CRM method was also used to perform a multi-scale investigation in the frequency domain of dusty argon RF plasmas with pulsed injection of organosilicon precursors (HMDSO). Variations of the electron temperature obtained by analysis of Ar 2p lines were observed over both the precursor injection cycles and the repetitive formation and loss dynamics of dust inside Ar-HMDSO plasmas. Finally, the CRM was recently updated to describe non-thermal plasmas at atmospheric pressure operated in He and Ar gas mixtures. In the case of He DBD, the values of Te were relatively high early in the discharge cycle (around 1.0–1.4 eV) and then much lower near discharge extinction (around 0.15 eV). For analysis of time-integrated (or cycle-averaged) OES measurements, Te was closer to the 0.15 eV values near the end of the discharge cycle, in good agreement with the values expected from theoretical predictions in the positive columns of He glow discharges at atmospheric pressure. More recently, similar experiments were performed in the γ and Ω modes of capacitively coupled He plasmas. When the discharge is

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sustained in the γ mode, Te is found to vary from 0.2 to 7.2 eV. In this case, high values of Te ($>$ 5 eV) occur only during a brief instant ($<$ 10 ns) in the high-voltage sheath. When the discharge is sustained in the Ω mode, Te is found to vary from 0.3 to 0.4 eV during the complete cycle.