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Quantitative diagnostics of reactive, multicomponent low-temperature plasmas[1]

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The special emphasis in this work is put on the quantitative determination of the plasma composition of an inductively coupled low temperature plasma (ICP). Several standard plasma diagnostic techniques were applied. As a test case for a multi-component low-temperature plasma argon-hydrogen as well as argon-hydrogen-nitrogen mixed plasmas were investigated. For steady-state plasma operation the ion density and electron temperature were determined with a single tip Langmuir probe. A multi-grid miniature retarding-field analyzer was used to measure the mass integrated ion flux. An energy-dispersive mass spectrometer - a so-called plasma monitor (PM) - was applied to sample ions from the plasma to derive the ion composition. The degree of dissociation of hydrogen and the gas temperature were derived from optical emission spectroscopy. The gas temperature was estimated by the rotational distribution of the Q-branch lines of the hydrogen Fulcher-α diagonal band for the argon-hydrogen mixed plasmas and from the second positive system of N_2 in argon-hydrogen-nitrogen mixed plasmas. The degree of dissociation of hydrogen was measured by actinometry. The influence of the substrate material of the counter electrode (stainless steel, copper, tungsten, Macor, and aluminium) on the atomic hydrogen concentration was investigated by OES. In addition, ionization-threshold mass spectrometry (ITMS) was used to determine the densities of atomic nitrogen (N) and atomic hydrogen (H and D). Pulsed plasma operation was applied to directly measure the loss rate of H, D and N in the afterglow from the temporal decay of the ITMS signal. From these data the wall loss probability of atomic hydrogen was determined. Furthermore, a zero-dimensional rate equation model was devised to explain the ion composition in these mixed plasmas with different admixture ratios. In addition to the experimental data on electron density, gas temperature, total pressure, atomic hydrogen density, and Ar, H_2, and N_2 fraction, the chamber geometry and the required collisional rate coefficients are input parameters for the model. The model was applied to calculate the ion densities and the electron temperature and describes the main features reasonably well supporting the validity of the plasma diagnostics applied.

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