Emission and absorption-based plasma diagnostic techniques for number density detection: Basics and Examples

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The absolute concentration (also called 'number density') of either neutral or ionized (both atomic and molecular) particles plays crucial role in understanding of the processes occurring in ionized and neutral gases. In particular, the populations of the ground, metastable and radiative states in various gaseous discharges may clarify the numerous related processes, including the gas flow dynamic, plasma kinetics, plasma-chemistry, etc., which are important for a number of applications. Last but not least, the number density in the plasma volume or in the post-discharge, found experimentally, may also be used as an input for modelling, serving for the further clarification of the plasma kinetics.

In this talk, the methods of optical spectroscopy used for atomic and molecular density quantification in the gaseous phase and related to spontaneous emission, optical absorption and laser-induced emission are discussed. A special attention is given to the laser-based methods, as they possess high spectral selectivity as well as high temporal and spatial resolution. Apart from the main physical principles, the talk is focused on the recent implementations, the validation procedures and the limitations of each technique. The examples coming from both the low- and high- pressure discharges used in the research and applications are also presented, such as the diagnostics of etching plasmas, aiming to get the density of several atomic species.

Among the non-intrusive diagnostic methods, the laser-based diagnostics involving single-, two- or three-photon absorption is of a particular interest, as the energy gaps corresponding to the visible, ultraviolet (UV) and deep UV spectral ranges can be covered by combining multiple laser photons. In addition, laser-based methods allow to perform two-dimensional density mapping [1, 2] as well as to calibrate the other diagnostic results [3, 4]. This is illustrated in Fig. 1 in the low-pressure plasma cases, including sputtering and rf-discharges. Fig. 1 shows the utilization examples of single-photon absorption laser-induced fluorescence (LIF) for density mapping and two-photon absorption laser-induced fluorescence (TALIF) for cross-checking the actinometry data obtained based on multiple O/Ar line ratios [3].

The methods targeted to determination of the ground state density and electron temperature using emission line ratios joint with Boltzmann solver are also elaborated. The recently proposed line ratio -based approaches allow to avoid the assumption of thermal electrons in plasma (i.e. Maxwellian distribution function), leading to calculation of a real electron energy distribution function and the corresponding ground state densities, based on the calculated energy distribution [5]. The applications of this routine to several gas mixtures are also discussed.

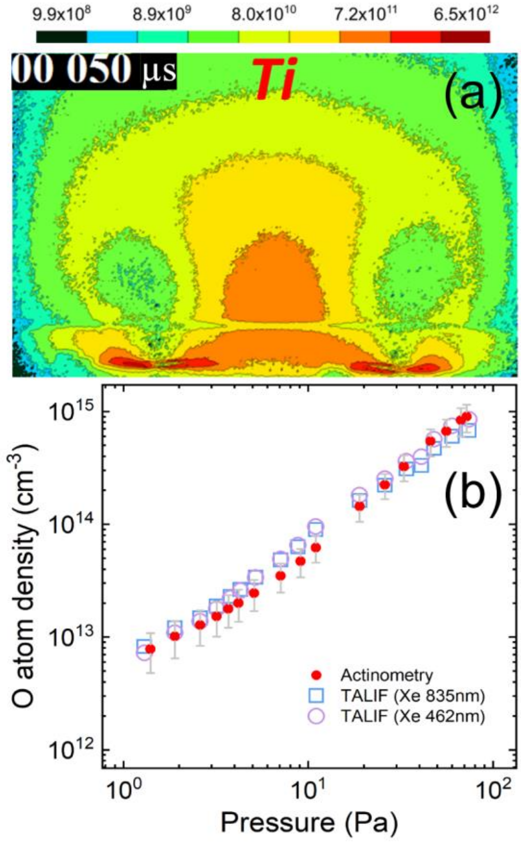

Figure 1. The Ti ground state density map obtained by LIF imaging and calibrated by atomic absorption spectroscopy (a); the O ground state density obtained by optical actinometry and cross-checked by TALIF of Xe (using two Xe transitions). Based on [2, 3].

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References

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