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Quantification of UV/VUV photon fluxes of hydrogen plasmas by spectroscopy and by collisional radiative modelling

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Photon fluxes are derived from absolutely calibrated UV/VUV spectroscopic measurements at a planar ICP discharge at 2 MHz in the pressure range of 1 Pa to 10 Pa. It is shown that the photon fluxes are comparable or even slightly higher than the ion fluxes onto a surface making it necessary to consider their impact for surface treatment processes. In order to predict photon fluxes for other parameters, collisional radiative modelling is used taking into account opacity effects of the Lyman lines. For the molecules ro-vibrationally resolved Corona models are used for deriving photon fluxes in different wavelength regions.

Hydrogen plasmas exhibit intense molecular and atomic radiation in the UV/VUV range. Besides the Lyman lines, the resonant Lyman (B–X transition) and Werner band (C–X transition) of the molecule are most prominent in the wavelength region 90 nm to 170 nm, partly overlapping each other [1]. The radiation of the continuum transition (a–b) in the triplet system is less intense but ranges from 120 nm to 600 nm with its maximum around 200 nm. In contrast to the radiation in the visible spectral range, the energy of the UV/VUV photons is much higher, ranging from several eV up to above ten eV. Hence, UV/VUV photon fluxes onto surfaces can become relevant for controlling surface treatment processes.

Previous investigations on photon fluxes and radiant power of UV/VUV photons in hydrogen and nitrogen plasmas for a cylindrical ICP [1] revealed that about 20% of the RF power delivered by the generator is radiated. The photon fluxes are in the range of 5×10^{20} $m^{-2}s^{-1}$ and thus close to the ion fluxes at the pressure of 3 Pa.

The present investigations focus on measurements in a planar ICP at 2 MHz and power levels up to 1 kW allowing for studying photon fluxes in the pressure range from 1 Pa to 10 Pa. Figure 1 shows that, at a pressure of 3 Pa, the photon flux in the VUV is distributed between the L_α line, the Lyman band (representing photons in the energy range of 6.5 – 9.5 eV) and the measured interval of the Werner band (photon energies between 9.5 eV and 10.3 eV) with slightly decreasing contributions. The measured values are compared to calculations based either on the collisional radiative model for the atoms (optically thin) or on ro-vibrationally resolved Corona models.

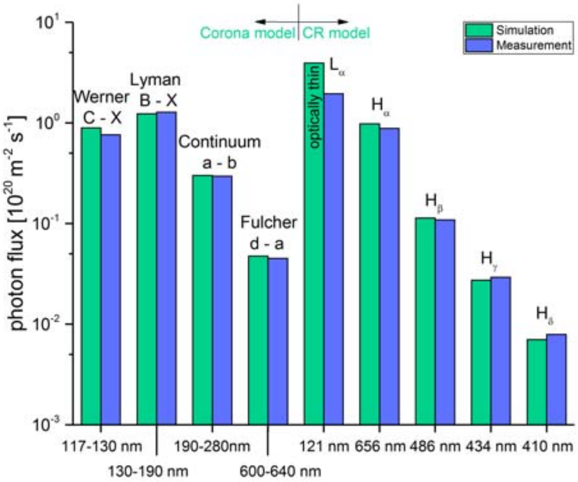

Figure 1. Photon fluxes measured in an ICP discharge at 3 Pa and 700 W RF power. Predictions obtained from CR (optically thin) and Corona modelling are also shown.

As the experiment is equipped with a RF phase-resolved voltage/-current measurement, the power coupled to the plasma and thus the RF efficiency can be quantified. The extension of the pressure range allows studying opacity effects. The predictive modelling capability of the collisional radiative models can be checked by comparison with measurements. Furthermore, the ro-vibrational Corona model for prediction of photon fluxes of the Lyman band is extended by considering the cascades from the EF-state.

Predictive modelling of photon fluxes are presented as well for a variation of electron density and temperature. The influence of the degree of dissociation is discussed.

References

[1] U. Fantz, S. Briefi, D. Rauner, D Wünderlich, Plasma Sources Sci. Technol. **25** (2016) 045006.