Stark broadening of hydrogen lines of a pulsed discharge in contact with a water surface

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Abstract: This work contains an investigation of electron density of an ambient pressure discharge in contact with a distilled water surface for a pin-water configuration. The electron density is determined by the width of the Balmer α and β emission lines of atomic hydrogen in the discharge. The electron density increases during the plasma treatment of water. Furthermore, the treatment of the water is investigated for different initial temperatures of the water, showing an enhanced activation processes for pre-heated water.

Keywords: Plasma-water interaction, Ambient air, Electron density, Stark broadening, OES.

1.Introduction

In the last decades, the interaction between gas discharges and liquids are studied intensively [1]. However, it is still not completely known what happens at the surfaces interface. Since a lot of research already has been performed, it is of importance to be able to compare different setups. One important plasma parameter to compare a discharge used in plasma models or other experimental results, is the electron density. There are different diagnostics that can be used to measure the electron density of a gas discharge. For the results in this work, optical emission spectroscopy (OES) is used to measure the width of the emission lines from energy transitions of hydrogen atoms.

2. Method

An advantage of optical emission spectroscopy is the non-evasiveness of the method, as it determines the electron density from the light emitted from the discharge itself. As the discharge is generated in ambient air above a water surface, a small amount of hydrogen atoms is present in the discharge gap. In this work, the width of the H_{α} and H_{β} of the Balmer series is measured to determine the electron density. The Stark broadening of an emission line is caused by interactions of charged particles with the emitting particles, but due to the high mobility of electrons relatively to the mobility of ions, Stark broadening is mainly caused by the electrons. An expression between the full width at half maximum (FWHM) of the Stark broadening and the electron density is used based the work of Nikiforov et al [2]. In equation (1) and (2) the electron density in cm⁻³ is expressed as,

$$n_{e,H_{\alpha}} \propto 10^{17} \left(\frac{\Delta \lambda_S}{1.098}\right)^{1.471}$$
 nm, (1)

$$n_{e,H_{\rm B}} \propto 10^{16} \left(\frac{\Delta \lambda_S}{0.946}\right)^{1.49} {\rm nm},$$
 (2)

where $\Delta \lambda_s$ is the FWHM of the Stark broadening of the emission line.

However, in the experiments, the broadening of the emission lines is the combined result of different broadening mechanisms like; Doppler broadening, Vander-Waals broadening, resonance broadening, instrumental broadening, and Stark broadening. The total FWHM of the H_{α} and H_{β} emission lines is a convolution of the Lorentzian and Gaussian broadening mechanisms. By estimating the values for the Doppler and Van-der-Waals broadening based on temperature measurements on this setup, neglecting the resonance broadening, and measuring the instrumental broadening, the Stark broadening can be determined from the measured total FWHM. By fitting a pseudo-Voigt profile through the measured emission lines, while keeping Gaussian part fixed (determined before the fitting procedure), a measure for the total Lorentzian FWHM of the line is obtained. Hence, subtracting other Lorentzian broadening mechanisms from this obtained width, results in the FWHM caused by Stark broadening, which is used to determine the electron densities presented in this work.



Fig. 1. Schematic of the OES setup used to measure spatially and temporally resolved values for the electron density.

3.Setup

To generate a discharge, a high voltage (HV) pulsed signal is applied to a tungsten needle electrode positioned above a Petri dish filled to the brim with distilled water. The distance between the needle electrode and the water surface is kept at 2 mm in this work. Embedded in the water is a stainless-steel plate electrode, connected to the ground through a hole in the bottom of the dish. The applied voltage is generated using a voltage amplifier, a HV pulse generator and a function generator to specify the pulse length and frequency of the applied pulse. For the results in this work, short unipolar positive and negative pulses are used, with a pulse width of $1.5 \,\mu$ s, repetition rate of 5 kHz

and amplitude of ± 6 kV. A schematic overview of the setup used to perform the OES measurements is demonstrated in figure 1.

In this work, measurements are performed with or without heating the distilled water prior to the measurement. To heat the water, 200 mL of water is heated in a microwave for 90 seconds, resulting in an initial temperature of 60-70 °C when the measurement starts.

4. Results and conclusions

Since no additional hydrogen gas is added to the setup, the intensity of the hydrogen lines is limited. Under these circumstances, it is important to achieve comparable results obtained from different hydrogen lines, which is achieved. Electron densities are measured in the order of 10^{14} to 10^{15} cm⁻³, increasing in value during the treatment of the water.

An interesting finding is the increased rate at which the water is activated for different initial temperatures of the distilled water. A likely explanation to this observation is the increased amount of water particles in the gas above the surface for pre-heated conditions. The increased humidity leads to different plasma chemistry [3], affecting the treatment process of the water.

5. References

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