Experimental research on atmospheric pressure surface–wave helium discharges

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1. Introduction

In recent years, a significant number of theoretical and experimental works have been conducted on the behavior of SWDs under atmospheric pressure. Most of them focus on argon plasmas [1] and only a very few experimental studies on the characterization of surface-wave neon discharge [2] sustained at this pressure conditions are found in the literature. In the case of He plasmas, only theoretical works have been published. This paper reports an experimental characterization of a helium SWD at atmospheric pressure using spectroscopy techniques to determine the densities and temperatures in the discharge. The results are compared to those obtained from a theoretical model [3].

2. Experiment Setup and Plasmas Parameters

The discharge was sustained in a quartz tube using a 2 slm flow of high purity He (99.999%). The tube having 5 and 6 mm inner and outer radii, respectively, was open at one end resulting in a plasma column at atmospheric pressure. Microwave (2.45 GHz) power (1880 W) was coupled by means of a *surfaguide* [4] and a power of was used to sustain a 7.5 cm (total length) plasma column.

The light emitted by the discharge was collected perpendicularly to the column axis by an optical fiber connected to the entrance slit of a Czerny–Turner monochromator of 1 m focal length previously calibrated and equipped with a 2400 grooves/mm holographic grating. A Hamamatsu R928P photomultiplier with spectral interval of 185–900 nm was used to observe HeI and H_β lines in order to measure the population of the He excited levels and the electron density. A charge coupled device (CCD), was utilized as detector of radiation for N_2^+ (391.44 nm) used as a tracer of gas temperature. Hydrogen atoms and N_2^+ ions were present as impurities in the plasma gas.

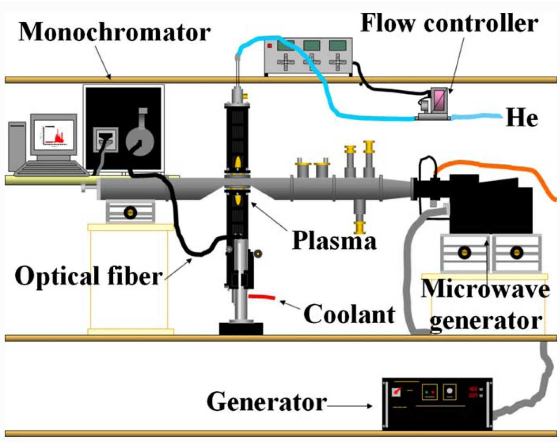

Figure 1. Experimental Setup

Electron density was measured from the Stark broadening of the Balmer series H_β line using the GC Model [5], whereas gas temperature was measured from the ro-vibrational spectra of the N_2^+ molecular ion using the spectroscopic data from [6]. Values of these parameters appear in Table I together with results obtained in previous experimental studies on the same type of discharges [7].

Table I. Electron density and gas temperature in an He surface wave discharge.

T_g (K)	n_e (10^{14} cm^{-3})
2200	0.4 – 0.8 (This work)
2000	0.5 (Ref. [7])

3. Atomic State Distribution Function and Thermodynamic Equilibrium

Figure 2 shows the atomic state distribution function (ASDF) including the population of the ground state 3.7×10^{18} cm^{-3} derived from the ideal gas law. The ASDF cannot be characterized with a single slope and several excitation temperatures (T_{exc}) are defined: *i)* the value of T_{exc} is 10900 K for levels below 22 eV (ground state and the first excited level experimentally observed), *ii)* the levels with excitation energy between 22 and 23.5 eV are characterized by a T_{exc} of 7500 K, and *iii)* a T_{exc} of 2500 K is found for the upper levels.

Using a collisional-radiative (CR) model [3] considering 34 He excited states and two ion species He^+ and He_2^+ with Boltzmann equation, the electron temperature calculated for our experimental conditions is 20800 K. This shows that the electron temperature is not in equilibrium with any of the excitation temperatures derived from the ASDF.

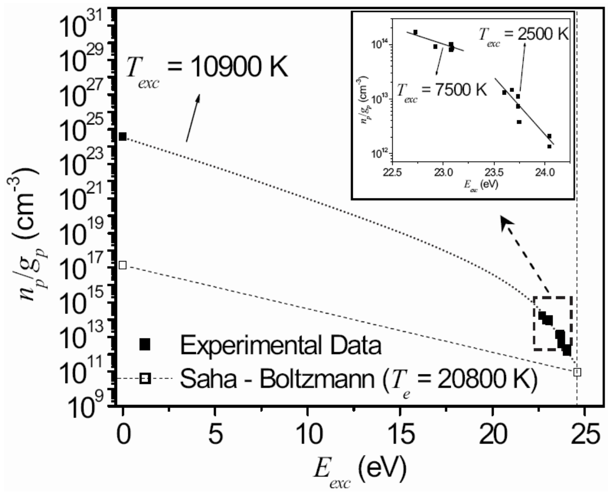

Figure 2. Boltzmann plot of the He lines including the ground level calculated from the ideal gas law and Saha–Boltzmann distribution at electron temperature of 20800 K and 5×1013 cm−3. Dotted line is provided as a visual aid for comparison purposes

The type of equilibrium and degree of departure from LTE can be determined by using the parameter b_p that measures the departure from equilibrium for each level p through the expression

$$b_p = \frac{n_p}{n_p^S} \tag{1}$$

being n_p the real (experimental) population and n_p^S the population provided by the Saha–Boltzmann equilibrium relation. Figure 3 shows both the experimental and theoretical b_p values for the same conditions as in Figure 2. Very good agreement between both experimental and theoretical b_p values can be observed. Besides, a significant departure from Saha–Boltzman distribution occurs, which denotes a severe departure from LTE.

Under our experimental conditions, the ASDF of the He atomic system is ionizing. Calculations from the CR code mentioned above show that in our experimental electron losses per electron through recombination (2.37×10^4 s^{-1}) is one order of magnitude larger than the diffusion losses (4.69×10^3 s^{-1}).

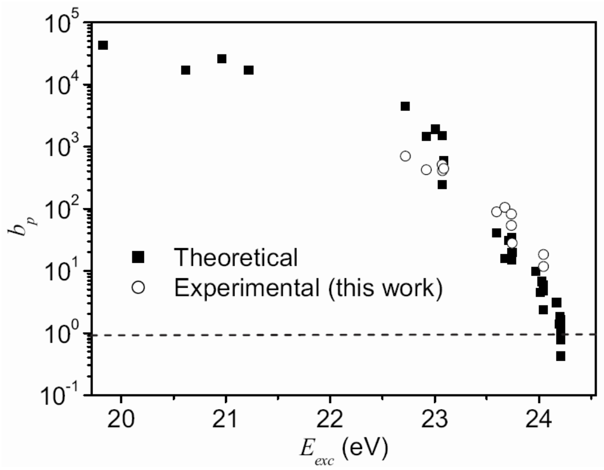

Figure 3. Theoretical and experimental b_p parameters for a He SWD under our experimental conditions

On the other hand, the ionization process in the plasma is the result of both electron-impact and associative ionization given by the following reactions, respectively

$$He^* + e^- \rightarrow He^* + e^- + e^- \quad (2)$$

$$He^* + He \rightarrow He_2^+ + e^- \quad (3)$$

From the CR model, the populations of He^+ and He_2^+ are 5.65×10^{11} and 4.93×10^{13} cm^{-3}, respectively, which shows that associative ionization (Eq.3) dominates electron impact ionization (Eq.2) by almost two orders of magnitude. The He_2^+ ions are thus destroyed by dissociative recombination, which generates an input of metastable He atoms. In this way, the ionization/recombination process is not controlled by three-body recombination and Saha balance is not verified.

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