Determination of He(2^3S) concentration in a surface barrier discharge: diode laser atomic absorption spectroscopy

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The two-dimensional distributions of metastable excited helium atom He(2^3S) concentration are measured in a surface barrier discharge by use of diode laser atomic absorption spectrometry. The transition at 388.975 nm $2^3S \rightarrow 3^3P^0$ is used for spaced resolved measurements of the He metastable atoms. The measured values of the number density were corrected due to different factors such as: the temporal appearance of the absorption signal, the absorption length and the diode laser beam profile and its interaction with metastables profiles.

1. Introduction

The determination of metastables density in high-pressure discharges is an important task because it is assumed that due to their long lifetime these excited atoms are the key species in generating atmospheric pressure uniform glows. Moreover, they are the precursors of excimer radiation generated mainly by three body collisions at atmospheric pressure. An easy method for the determination of the He(2^3S) atom concentration is the absorption of the light with wavelength 388.975 nm by electronic transition $2^3S \rightarrow 3^3P^0$. Recently broadly used is the diode laser atomic absorption spectroscopy (DLAAS). This is a non-invasive method offering the possibility for a direct determination of the temporal and spatial distribution of the excited atoms in the discharge. Moreover, through the analysis of atomic absorption line profiles some other plasma parameters like the electron density or the gas temperature can be derived. The diode lasers have very narrow emission band with tunable wavelength by diode current and operation temperature. This feature allows a precise sampling of the entire absorption line needed for the determination of the metastables concentration. The difficulties of the diagnostics in high-pressure surface barrier discharges (SBD [1]) are small dimensions comparing with the laser beam cross-section, temporal density variations of the absorbtion signals, weak signals and complex internal structure of this discharge. In this work the principle of measuring the absolute number density spatially resolved is presented. A detailed discussion of the correction factors influencing the value of the density is analyzed.

2. Experimental arrangement

The experimental setup used for the DLAAS in this work is as the one described in detail in [2]. The beam of a 778 nm laser diode (external cavity TOPTICA system) is used after frequency doubling with a Lithiumniobat crystal to sweep the wavelength, allowing to collect the data of the entire Doppler and pressure broadened triplet line. The discharge operates in He in the range from 50 to 1000 mbar with flow rates between 200 and 500 ml/min. The applied ac voltage is between 500 V and 1.5 kV and the power of up to 100 mW. Commonly, a sinus waveform voltage is used (see complementary paper [3]). For our diagnostic purposes, a square wave voltage was applied in order to have only one current pulse on every half period of the applied voltage and to control the behavior of the excited atoms. The linear structure was placed in a closed chamber provided with the possibility of controllable horizontal (x) and vertical movement (y), see Figure 1 . The absorption signals were either directly measured spatially and temporally resolved or using a lock-in amplifier when the absorption was smaller than 1 %. A typical absorption signal at low pressure, with the marked lines of the triplet is also shown in Figure 1.

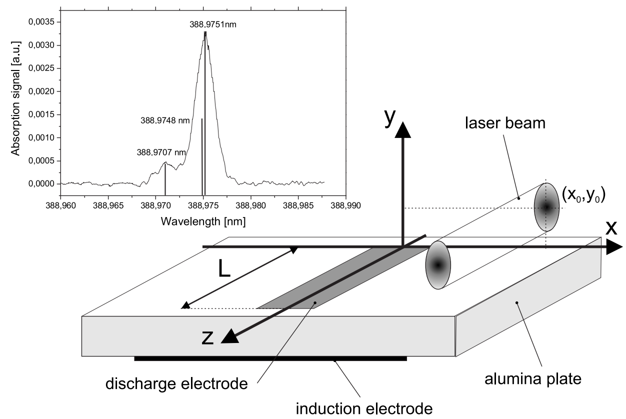

Figure 1: Cartesian coordinate system in SBD for DLAAS measurements and an absorption profile.

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3. Correction factors for absolute density of metastables

The value of the He metastables density is strongly influenced by the lock-in detection, the appearance of the discharge and the diode laser beam profile. All these factors will be discussed in the following.

a) Lock-in detection

Whenever the absorption signals were smaller than 1 %, the lock-in detection had to be used in order to improve the sensitivity of the measurements. The plasma is self-modulated and consequently the absorption is modulated with the frequency of the applied voltage. However, the absorption signals have a shape given by the excitation/deexcitation processes in the plasma and not the sinus form required by the lock-in. Therefore the right frequency has to be used as reference frequency for the lock-in amplifier and the signal has to be corrected due to the non-sinusoidal modulation. This is normally done by analyzing the components of the Fourier transform of the absorption signal and comparing the Fourier coefficients with the direct absorption. Due to the change of the temporal absorption line shape with the pressure, this analysis has to be done every time. Our measurements, changing the pressure from 50 to 700 mbar, showed that this correction factor increases the value of the density with a factor 4 to 8.

b) Effective absorption path

The SBD is not homogeneously distributed along the entire length of the discharge electrode, but shows depending on pressure, different distributions of more and less dense plasma zones [3]. Therefore, an effective length has to be defined connected with these zones in the discharge. As a consequence, the absorption length can be a few times smaller that the geometrical length. The absorption measurements across the z direction were not possible, because the optical path perpendicular to the electrode is too short to obtain a sufficient absorption signal. For this reason the emission intensity profiles obtained from the top-view ICCD pictures (see Figure 2 for 100 and 1000 mbar) and normalized on its maximum value can be used

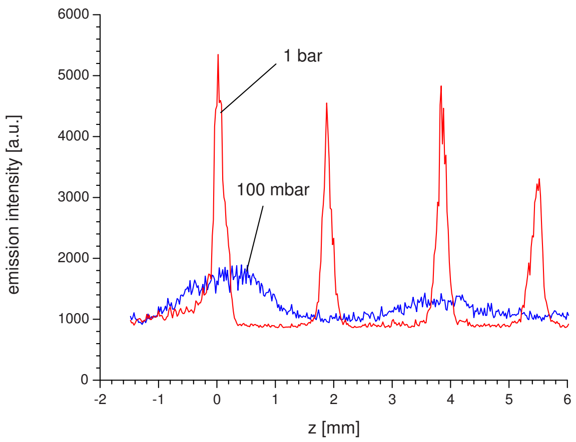

Figure 2: The light emission intensity profiles along the left SBD electrode edge for 100 and 1000 mbar.

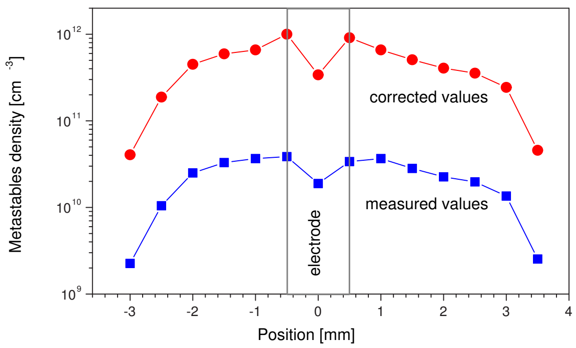

Figure 3: Horizontal distribution of metastables density for 300 mbar.

instead for estimation of the effective absorption path. The effective absorption path as a function of pressure measured at the edge of one electrode is shown in Figure 2 . The effective absorption length is almost the same as the geometrical length for low pressures but it is decreasing drastically at high pressures reaching a value of only 30 % of the geometrical one at 1 bar. Due to this correction, a further increase in the value of the density with a maximum factor of 3 (corresponding to 1000 mbar) can be achieved. This correction strongly affects the values of the density measured at the edges of the electrodes and their influence decreases moving along the x direction.

c) Overlapping of the beam and discharge

The intensity profile of the laser beam was measured and fitted in the (x, y) plane by a double Gaussian profile with maximum intensity I_0 at position (x_0, y_0):

$$I(x,y) = I_0 \exp[-(\frac{x-x_0}{\sigma_x})^2 - (\frac{y-y_0}{\sigma_y})^2] \qquad (1)$$

where $\sigma_x = 330$ µm and $\sigma_y = 780$ µm respectively.

The plasma density distribution depends strongly on pressure (see [4]). For pressure close to atmospheric, the thickness (dimension y) of the discharge is comparable with σ_y. Only small part of the beam is overlapping with the metastables containing zone. To obtain the realistic values for the maximum metastables concentration needed for discharge modelling, the correction factor taking into account the convolution of the beam intensity distribution and metastables distribution in x, y plane should be used.

Taking into account all these corrections, in Figure 3 , the density of metastable He atoms is shown with and without correction. It can be seen that the maximum value of the density is a factor 25 higher than the initial measured value with the lock-in.

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