Determination of He(2^3S) concentration in a surface barrier discharge: time resolved analysis

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The concentration of He(2^3S) in a helium surface barrier discharge is determined by use of diode laser atomic absorption spectroscopy at wavelength 388.9 nm. The variation of the time resolved He(2^3S) concentration is compared with discharge light emission intensity and with discharge current signal. The role of the metastable excited species for sustaining the He-SBD is discussed.

1. Introduction

Due to its durability and simplicity, the surface barrier discharge (SBD) electrodes are very promising for technological applications under atmospheric pressure [1]. The dielectric barrier discharges (DBD) in helium allow generation of the atmospheric pressure glow discharge (APGD). Due to the long-living metastable excited He(2^3S) atoms, the APGD occurs as a homogeneous, cold plasma [2]. The DBD mechanisms can be investigated by diode laser atomic absorption spectroscopy (DLAAS) [3]. In this work the time dependent variation of discharge current, light emission signal and absorption signal at wavelength 388.9 nm, related to He(2^3S) concentration (see [4] for details), are discussed. For 2D metastables distributions see [5].

2. Discharge structure

Despite of the homogeneous appearance of an SBD operated in helium, the fast ICCD pictures show its distinct structure (see Fig. 1). The discharge consists of spots of high density plasma positioned at the edge of the discharge electrode over its surface. To each of this electrode spots belongs a much larger area over the induction electrode (see gray patches in Fig. 1) [6]. During each period of the kHz high voltage excitation, the current is flowing from the electrode through the discharge spot and is distributed over the ceramics surface until the limit for charge accumulation is reached. It can be observed, that larger and more dense spots belong to larger patch areas over the induction electrode. With decreasing pressure the number of spots is decreasing but their area gets larger and they shift from the discharge electrode edge toward the electrode center. Similar multi-spot patterns are observed also for much shorter ICCD camera exposure times, down to 10 μs. Such short exposure excludes the recording of several subsequent partial discharges in one picture. It proves, that in each excitation half-cycle many spot-patch couples exist concurrently. Valuable information about the dynamics of the SBD can be obtained from time resolved observation [7].
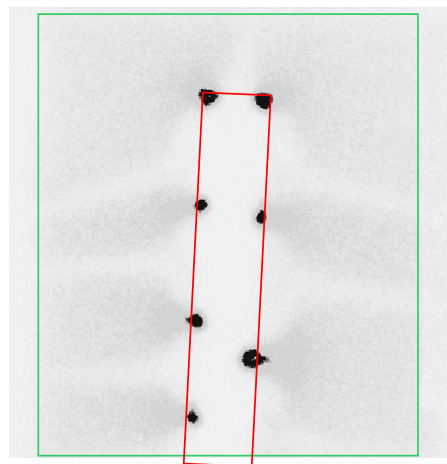

Figure 1: Negative ICCD picture of the SBD excited by 700 V, 8 kHz pulsed signal. Picture is taken for pure helium under atmospheric pressure with exposure time of 10 ms. The outer and inner counter depict the edges of induction and discharge electrode respectively.

3. Sinusoidal excitation

The sinusoidal, resonant excitation is frequently used for industrial DBD applications due to its high efficiency [8]. In Fig. 2 the total light emission of the SBD excited by such signal is displayed. For 100 and 300 mbar the emission maxima occur in both cathodic and anodic half-periods. For 100 mbar the emission is stronger during cathodic, for 300 mbar - during the anodic half-period. For pressure higher than 300 mbar only during anodic half-period the strong light is emitted. The maximum emission intensity decreases with pressure. The time needed for achieving the maximum emission is growing with increasing pressure due to decreasing species mobilities. The relative variations of the emission intensity decrease with decreasing pressure, because the increasing lifetime of the metastable species (see Fig. 3) prohibits the complete extinguishing of the discharge.
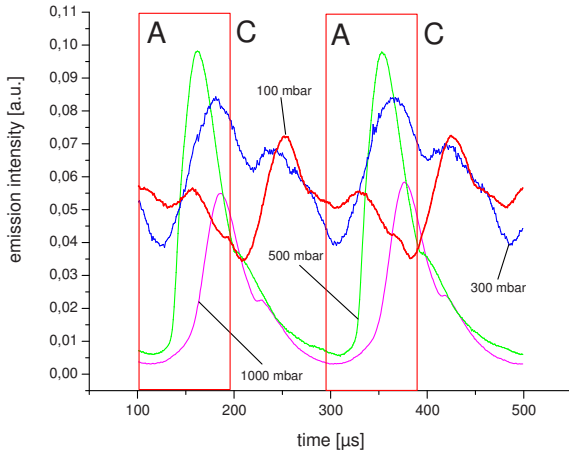
Figure 2: Light emission intensity of the SBD, excited by sinusoidal signal with amplitude of 500 V and frequency of 5 kHz, displayed as a function of time for pressures from 100 to 1000 mbar. A and C in the diagram depict the anodic and cathodic half-period of the discharge electrode excitation.

4. Reaction on a voltage pulse

In Fig. 4 the relative values (divided by maximum value) of the discharge electrode voltage, current, absorption signal measured over the electrode and total light emission intensity for SBD excited by voltage pulse at 100 mbar are displayed. The signal length on 1/e hight is 1.1, 8.4 and 25.7 μs for current, light intensity and absorption signal respectively. The current flow duration is determined by charging up of the ceramic surface. This time constant depends on the charged capacity and the plasma conductivity. In this discharge phase a large amount of metastable species is generated. They are decaying in the following afterglow phase of the partial discharge. The light emission is related to the electrons, which are present in the discharge as long, as the two body ionization resulting in electron release is the dominating He(2^3S) destruction mechanism. After this period of time, the
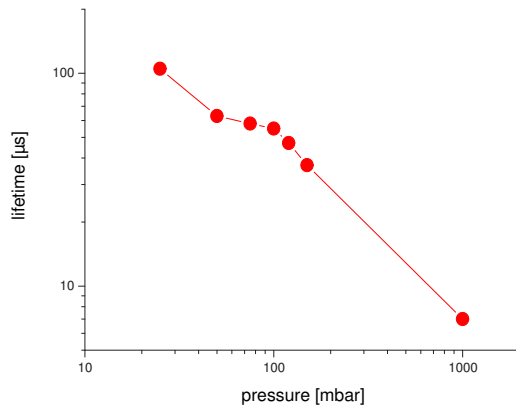

Figure 3: The lifetime of He(2^3S) determined from the 1/e width of the absorption signal as a function of pressure. Data for 1000 mbar is taken from [7].
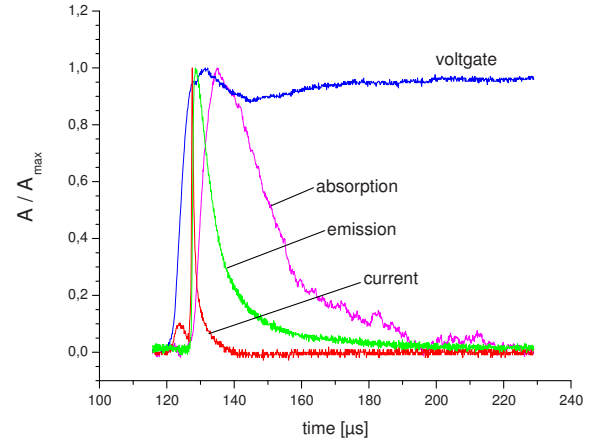

Figure 4: Relative values of discharge electrode voltage, current, absorption signal and total light emission intensity vs. time for 100 mbar.

three-body associative excitation transfer dominates, which is not causing any charge release. Under considered discharge conditions (pressure of 100 mbar) the transition between these two loss mechanisms occurs at metastable concentration of about 5×10^{11} cm^{-3}. This value is calculated by use of the rate coefficients taken from [9]. Because this transition can be recognized in the logarithmic plot of the absorption as a connection point of two linear slopes, it can be used for calibration of the absorption signal. The absorption maximum from Fig. 4 corresponds in such case to He(2^3S) concentration of 1.6×10^{12} cm^{-3}.

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