Spatial and temporal distribution of excited Ar atoms in a linear dielectric barrier discharge

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Introduction

In the recent years, the dielectric barrier discharge (DBD) was intensively used for various applications, e.g., ozone generation, plasma display panels, excimer sources, surface treatment and pollution control [1]. The basic configuration of these types of discharges is similar, but there are differences in the working parameters such as pressure, distance between the electrodes or the type of dielectric layer.
The dielectric barrier discharge presented in this paper was described in detail elsewhere [2,3]. Shortly, the discharge consists of two aluminium electrodes (thickness 50-100 nm) covered with glass type dielectric layers (thickness around 20 µm). The length of the electrodes is about 50 mm and the width of electrodes less than 1 mm. At voltages higher than the breakdown voltage, a quasi-continuous transient plasma is formed along the electrodes. The discharge is working in the low and medium pressure range (10-100 mbar). This type of linear discharge presents excellent capabilities to be used in analytical spectrometry [2].
The first excited states of noble gases (in Paschen notation $1s_2$, $1s_3$, $1s_4$, $1s_5$) play an important role in the plasma processes. The distribution of excited atoms on these levels can give information about the formation of the discharge and the efficient regions of the plasma.

Experimental arrangement

The study of the excited species in the linear dielectric barrier discharge was performed by absorption using diode lasers which are suitable for atomic spectroscopy [4]. The discharge was driven by a square-wave voltage generator with a frequency between 5-20 kHz and voltages up to 2 kV_{pp}. The discharge in Ar was investigated in a flowing gas system.
The experimental arrangement for the spatial and temporal evolution of the excited Ar atoms consists of a collimated laser beam from the laser diode passing directly through the discharge along the electrodes. A few cm from the discharge a lens (f=16,7 cm) is placed for a magnified image of the discharge region on a pin-hole of 200 µm placed at about 1 m away from the lens. The pin-hole can be moved up and down providing different regions in the discharge to be investigated. The absorption signals are detected with a fast Hamamatsu photomultiplier behind the pin-hole and recorded by a Tektronics oscilloscope (sampling rate of 2 Gs/s). Using this arrangement, the spatial resolution of the discharge is about 30 µm and the temporal resolution is less than 100 ns.
The laser diode was tuned to two transitions of Ar at 800.838 nm ($1s_4$-$2p_6$) and 801.699 nm ($1s_5$-$2p_8$). Since the transition initiated from the metastable level was optically thick, we restricted our investigations to the measurement of Ar atoms in the resonance state.
From the measurement perpendicular to the electrodes (small absorption length) the absolute density of both resonant and metastable atoms was found to be 2×10^{12} atoms/cm^3 and 10^{13} atoms/cm^3, respectively, at the maximum of the absorption signal around 12 µs after the start of the current pulse.

Results and discussions

Due to the non-Maxwellian distribution of the electrons at the beginning of the current pulse, the temporal and spatial variation of the electron density, the gas temperature and the excited atoms the dielectric barrier discharge is a very complex system. The high electron density causes efficient dissociation of molecules and the excitation of atoms.
Figure 1 presents the absorption signal measured close to the cathode, in the middle of the discharge and close to the anode for a period of the applied voltage. It can be noticed that the structure of the signal is temporally different between anode and cathode on each half period of the applied voltage. The obtained curves are similar for each temporally anode as well as cathode. The

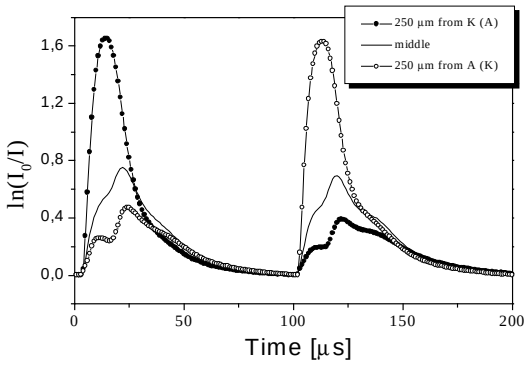

Fig. 1 Transient absorption signals in one period of the applied voltage measured in the middle between and 250 µm from each electrode (200 ml/min, 30 mbar, 5 kHz)

highest excited atom density is always in the vicinity of the cathode.

The spatial and temporal evolution of the excited Ar species on the resonant $1s_4$ level is strongly dependent on the discharge parameters, as, for example, the gas flow and pressure. The influence of the flow rate at constant pressure is shown in Fig 2. It represents the absorption $\ln(I_o/I(t))$ temporally and spatially resolved. At 500 ml/min the signal is 3 times longer than at 50 ml/min, while the spatial behaviour is comparable. Changing the pressure at a constant flow rate, as is displayed in Fig 3, it can be noticed that the maximum of the relative density is moving closer to the cathode with increasing pressure. This displacement is similar to a d.c. discharge, where the negative glow (maximum density of excited atoms) is moving with higher pressure towards the cathode

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Conclusions

The diode laser absorption spectroscopy, as presented here, allows the spatially resolved measurement of excited atoms even in compact discharges with long absorption length. It was possible to measure the spatial and temporal distribution of Ar atoms in its resonance state for different plasma parameters in a linear dielectric barrier discharge.

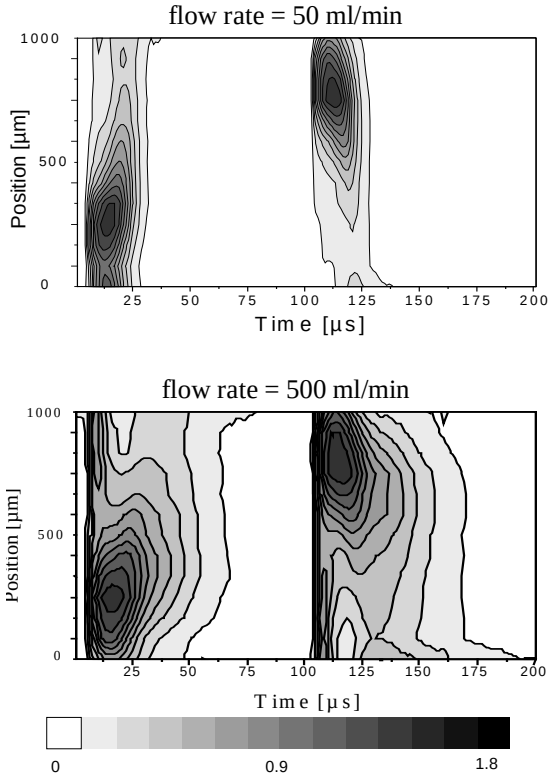

Fig. 2 Dependence of resonant absorption signal on Ar flow rate at p=40 mbar

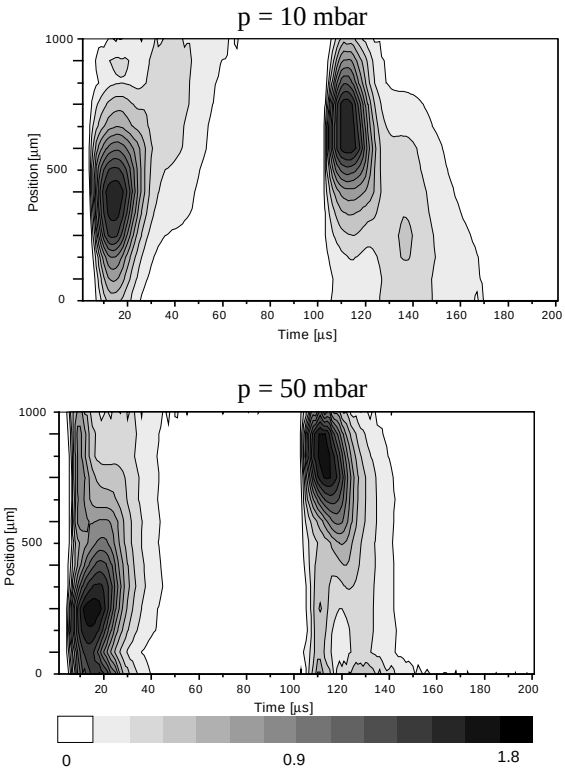

Fig. 3 Dependence of resonant absorption signal on Ar pressure at 100 ml/min

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