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ELECTRIC FIELD MEASUREMENT IN THE CATHODE FALL REGION OF A DIELECTRIC BARRIER DISCHARGE IN HELIUM

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Abstract. Dielectric barrier discharges in helium is investigated by temporally and spatially resolved optical emission spectroscopy. Focus of our investigation was He I 447.15 nm line which can be used in electric field measurements. At maximum discharge current the spatial line intensity distribution and the electric field distribution are characteristic for the cathode fall region. Estimated electric field strength distribution is in agreement with theoretical calculation. Temporal evolution of He I 447.15 nm line during the breakdown is also studied.

1. INTRODUCTION

The barrier discharge is one of the plasma sources at high pressure widely applied in thin film deposition, surface modification, and plasma chemistry. It is a low frequency alternating current (AC) discharge in a narrow gap between two electrodes of sufficiently large area covered by a dielectric barrier. Various configurations of electrodes are used in the barrier discharge; the plane configuration is most simple and suitable for an experimental investigation and a theoretical description. At certain conditions this discharge is homogeneous in the plane of electrodes. The homogeneous barrier discharge is very attractive for the applications in plasma technologies, especially in surface treatment. It has become the object of the intensive experimental and theoretical investigations, see e.g. Massines et al. 1998, Golubovskii et al. 2003, Navrátil et al. 2006. The homogeneous barrier discharge in helium is characterized by the narrow current pulses of large (tens of milliampere) amplitude; there is only one pulse per half-cycle of the external voltage. In this mode of the discharge, the spatial structure containing the cathode fall, Faraday dark space, and positive column, develops in the phase of maximal current, see Massines et al. 1998. This circumstance allowed referring to this mode of discharge as the atmospheric pressure glow discharge. In this work we studied development of a barrier discharge in helium and measured electric field strength nearby the cathode.

2. EXPERIMENT

The discharge was generated in a parallel plane discharge configuration consisting of two metal electrodes (50 × 50mm) both covered by a 0.65 mm thick alumina layer (105 × 105 mm). The electrodes were fixed by two space holders made of glass ensuring a constant discharge gap of 2 mm. The discharge cell was placed in a vacuum chamber that was evacuated down to 10^{-3} mbar first and then filled with helium (purity

99.996 %) at 200 mbar pressure. The gas was directly injected into the discharge volume with a flow rate of 2 l/min. The discharge was driven by a pulse voltage of frequency 5 kHz. The applied voltage and the discharge current were measured by Tektronics TDS 3032 (300 MHz bandwidth, 2 GSamples/s) digital oscilloscope. The applied voltage was measured via a 1000:1 voltage probe; the current was monitored by measuring the voltage across a 50 Ω resistor connected in series with the discharge cell. For time resolved emission measurements, projection optics are used to image the whole electrode gap region onto the entrance slit of a 1m spectrometer and detected using an intensified charge coupled detector (ICCD). ICCD is triggered with a time delayed pulse generated initially by the power supply. Recorded images consist of 50 accumulations each made of 50000 gates per exposure. The gate duration was 80 ns.

3. RESULTS AND DISCUSSION

Typical current and voltage oscillogram of DBD in pure helium during a single cycle is shown in Fig. 1. The current is characterized by one pulse per cycle with the amplitude of 60 mA and the rise time 0.3 μs. At first the current pulse has quick decrease ($\sim$ 1 μs) followed by a slower decrease ($\sim$ 10 μs). The applied voltage has one negative pulse during the cycle. The voltage oscillations is due imperfection of power supply. Before the breakdown i.e. before the current peak starts to rise, the applied voltage reached values of 0.5 kV. In Fig. 1b an enlarged view of the current oscillogram is shown and the time interval in which the discharge is spectroscopicaly investigated is marked.

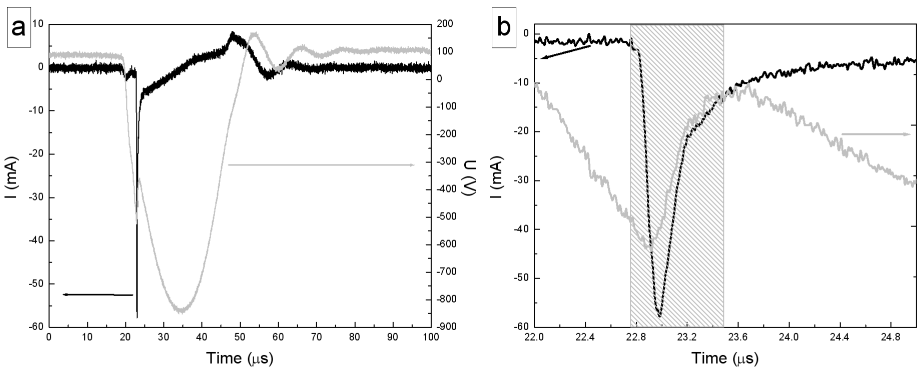

Figure 1: a) Applied voltage and discharge current variation during one cycle. Pressure 200 mbar.

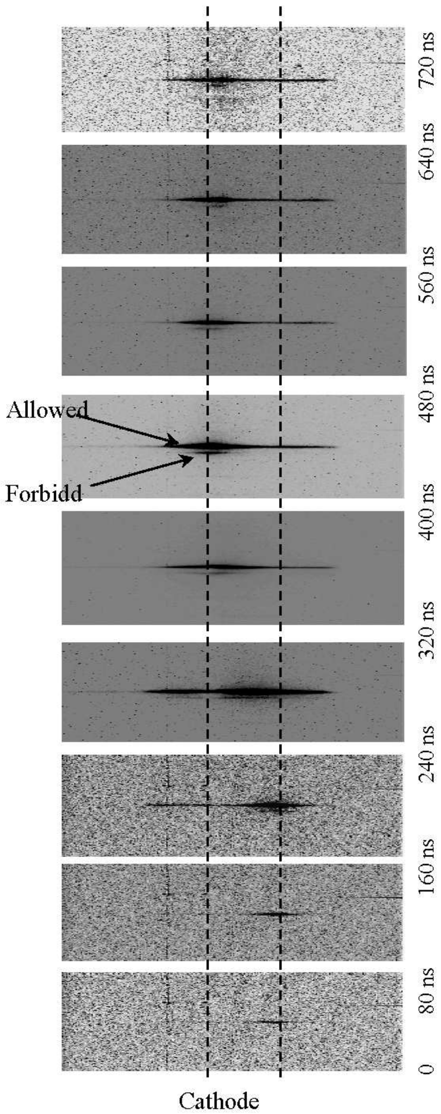

Figure 2: Spatial and temporal evolution of the He I 447.15 nm.

Figure 2 shows the evolution of He I 447.15 nm line in the time interval marked on Fig. 1b. In our earlier papers, see Kuraica and Konjević 1997, Kuraica et al. 1997, we used Stark splitting and shifting of the He I 447.15 nm line and its forbidden component in order to measure electric field strength in the cathode fall region of an analytical glow discharge. Time evolution and space distribution of the He I 447.15 nm line can give information about evolution of the electric field in the DBD during the breakdown. In Fig. 2 can be observe the characteristic phases of the breakdown, see

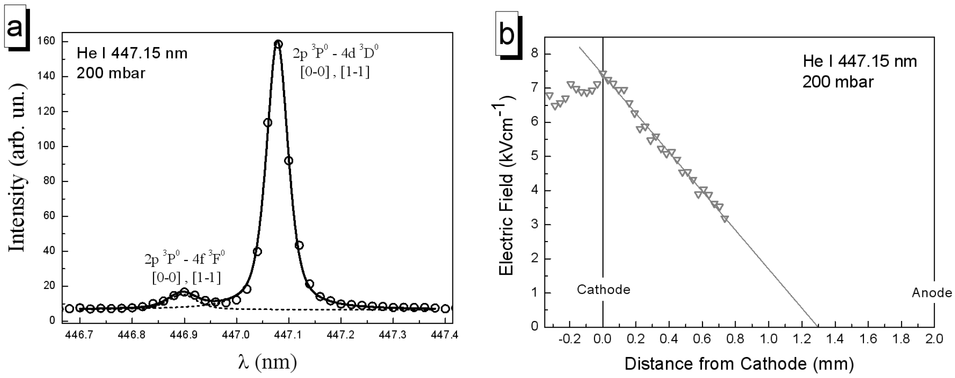

Figure 3: a) Typical π polarized spectra of He 447.1 nm allowed and its forbidden component.

Golubovskii et al. 2003. At t < 160 ns the maximum of the ionization rate is nearby the anode. In this phase, the electric field is weakly disturbed by spatial charge, and the electron density increases from the cathode to the anode exponentially. Further, an ionization wave appears nearby the anode which can be observed by higher intensity of the He I 447.15 nm line nearby the anode. The ionization wave moves towards the cathode at 160 < t < 400 ns. In this phase, the field nearby the cathode begins to grow. As the ionization wave reaches the cathode (t $\sim$ 400 ns), the spatial profile of the electric field changes abruptly. The structure of the discharge becomes similar to that of an ordinary glow discharge, containing a cathode fall, observable by the large intensity of the He I 447.15 nm line forbidden component in a narrow region near the cathode.

Following the method that demonstrated Kuraica and Konjević 1997, the electric field strength, in the time of maximal current, is determined using Stark splitting of He I 447.15 nm line polarized in electric field direction (π polarized). An example of a typical π polarized spectra of He I 447.15 nm allowed and its forbidden component, recorded in the DBD in helium is shown in Fig. 3a. Both components of the line are fitted with pseudo-Voight profiles (sum of Gauss and Lorentz profiles) in order to estimate peak-to-peak distance according to which the electric field is determined. Spatial distribution of the measured electric field strength in the vicinity of the cathode is presented in Fig. 3b. Negative values for the distance from the cathode is consequence of light reflection from the alumina layer and has no physical meaning. The electric field values and its spatial distribution is comparable with the theoretical calculation see e.g. Massines et al. 1998, Golubovskii et al. 2003, that are made for 1000 mbar pressure.

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