OPTICAL INVESTIGATIONS OF HIGH PRESSURE GLOW DISCHARGES BASED ON MSE ARRAYS

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Abstract

The Micro-Structure-Electrode (MSE) arrays are providing a non-thermal high pressure plasma. These arrays consist of a matrix of holes perforated in a thin multilayer made out of two metallic foils separated by a dielectric. The holes diameter and the thickness of the insulator spacer need to be around 100 µm to allow for the MSE operation at pressure ranging from 0.1 to 1 bar and above.

In this work single direct current microdischarges and systems of parallel operated holes in argon at 0.2 bar have been optically investigated. The spatial distribution of the emitted light has been monitored by a digital camera connected to an optical microscope. The UV photon emission has been recorded by a position sensitive photon detector allowing for space and time resolved measurements. Its time resolution of about 1 nsec makes possible the investigation of fast processes, e.g. the constriction of the discharge. Due to its typical position resolution of 100 µm, this detector needs to be used in combination with an optical system allowing for the magnification of the discharge area. The optical appearance show a stable, volume filling glow discharge, fact proved also by the typical current–voltage characteristic.

1 Introduction

In order to generate large area, dc driven glow discharges at elevated pressures, Micro-Structure-Electrode (MSE) arrays have been implemented [1, 2]. The presently used microstructures consist of a regular arrangement of holes perforated in a poliymide foil metal clad on both sides. Their typical dimensions are: the holes diameter 100 µm, holes pitch 1.5 to 3 mm, electrodes thickness 100 µm and 50 µm thick dielectric layer. Due to these small dimensions, the strong electric field needed for breakdown at high pressure [3, 4] is locally achieved by moderate applied voltage (hundreds of volts). Stable direct current glow discharges have been produced in rare gases (e.g. argon, helium, neon) and air at pressures between 0,1 bar and atmospheric pressure. The discharge current can vary from 0.1 to 20 mA/per hole at operation voltage between 150 and 400 V. Average current densities up to 100 A/cm^2 have been estimated. Depending on the application, single microdischarges or modules with a large number of parallel connected holes can be operated in different gases, in steady or flow mode.

The high working pressure together with the non-thermal character of the MSE induced plasma make it very promising for many applications, e.g. surface processing, plasma chemistry, unconventional light sources.

2 Optical investigations

2.1 Experimental setup

The electrodes are made out of copper 100 µm thick and have perforations of 100 µm diameter. The thickness of the dielectric layer (Kapton) is 50 µm and set the distance between the two electrodes. To make possible the observation of individual discharges the spacing between holes (pitch) was chosen 1.5 or 3 mm.

Single-hole structures as well as arrays with up to 200 parallel connected holes have been mounted in a 1000 cm^3 stainless steel reactor. Two quartz windows laterally mounted are providing optical access to the MSE sustained discharge. The reactor can be evacuated to 10^{-5} bar and filled with different gases or gas mixtures, in steady or flow mode, at working pressures from 0.1 to 1 bar. The experiments described here have been performed in argon, static conditions. A dc power supply TC951 was used to bias the cathode through a load resistor of 100 kΩ.

2.2 MSE sustained discharge

A single microdischarge operating in Ar at a pressure of 0.2 bar has been studied. The discharge has been recorded end-on at the cathode side by a digital camera connected to an optical microscope (total magnification 120). The current-voltage characteristic of the MSE sustained discharge (Fig. 1) is similar with the well-known characteristic of a low pressure glow discharge. At low current values presents a Townsend mode followed by a transition to a normal glow discharge. The axial electric field begins to be distorted by the space charge inside the cathode and a strong radial electric field develops. Accordingly, the optical appearance of the discharge changes from diffuse (Fig. 1a) to structured (Fig. 1b). Up to now the current can be increased for more than one order of magnitude at constant voltage, a typical signature for a normal glow. The discharge extends out of the hole over the cathode surface (Fig. 1c,d). Thus the active surface of the cathode is enhanced an increase in current is possible without need of higher sustaining voltage.

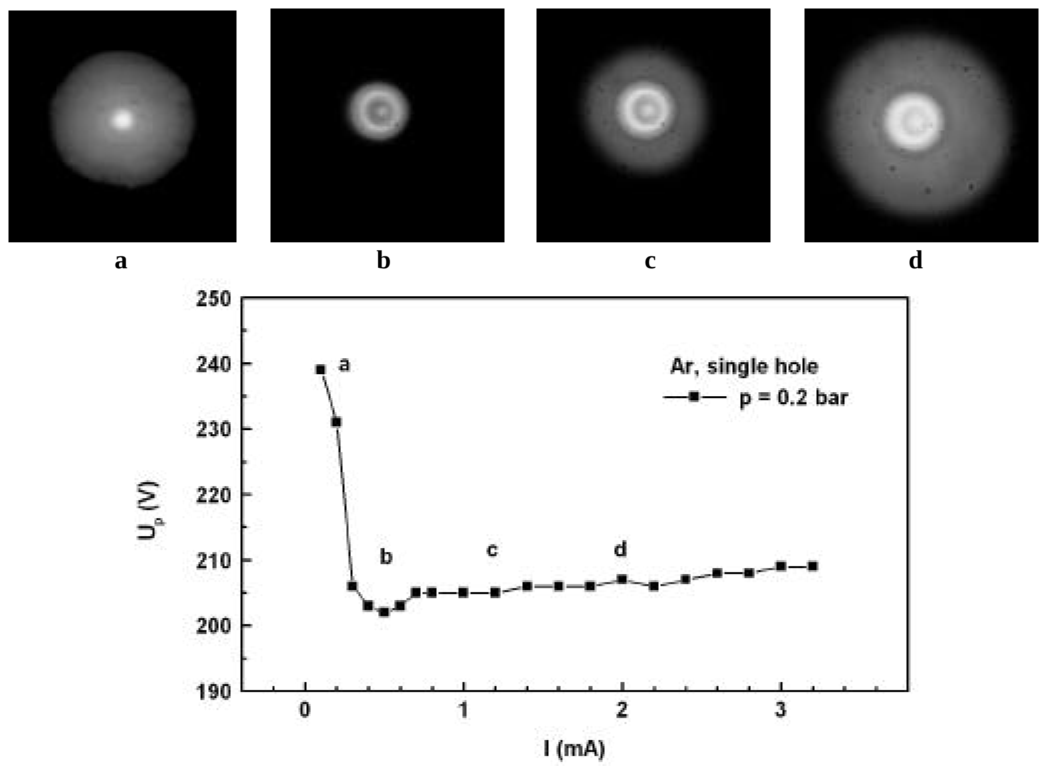

Fig. 1: Optical appearance of a MSE sustained discharge (end-on cathode) and the corresponding current-voltage characteristic.

For further rise in current an abnormal glow regime (not present in Fig. 1) can be observed. It has a resistive U-I characteristic and is associated with the contraction of the discharge inside the hole. This very high energy density leads often to the damage of the MSE therefore the operation of the discharge in this mode is usual avoided.

2.3 Position sensitive UV detector

The position sensitive detector presently used consists of a sealed MCP image intensifier [5] coupled through a semi-conducting Ge layer with a wedge-and-strip anode placed outside. The photons are passing through a quartz (suprasil standard, cut-off wavelength 165 nm) window and are converted in electrons by a K_2SbCs photocathode. This bialkali converter can be used also in visible up to 600 nm but has its maximal spectral sensitivity at 400 nm. The dark emission rate is about 15 el./cm^2/s at environmental temperature and it can be reduced cooling the detector. A chevron MCP assembly (3 MCPs in Z-stack configuration) amplifies usually the electrons leaving the photocathode, its typical gain being about 10^6. It is known that near UV photons are also able to release electrons from the MCP but with very low efficiency (less than 2%). In order to obtain the picture of the UV radiation emitted from the microdischarge one have to impede the electrons created in the photocathode to arrive on the MCP. To ensure that only UV photons are reaching the channel plate the bialkali converter was always kept at positive potential. The electron cloud emerging from the MCP is not collected directly on the wedge-and-strip anode but on a high resistance sheet (image charge detection [6]). This Ge layer of about 200 nm deposited on the backside of the assembly makes the coupling to a position sensitive anode, wedge-and-strip type in our case. The wedge-and-strip anode contains three distinct electrode patterns, where position information is obtained by charge division. These patterns are wedges and rectangular arrays (strips with increasing width). The rest of the surface is covered by the space between these two structures, called "meander". All three structures are individually contacted. The three out-coming signals are amplified by a set of charge sensitive pre- and main amplifiers and processed simultaneously by individual channels of an analog-to-digital converter (ADC). For every event the time and position information are monitored via a PC controlled data acquisition and analysis program based on CAMAC hardware and the COBOLD software [6]. The resolution is limited by the signal-to-noise ratio and the range of the ADC. With low noise amplifiers as CATSA an absolute position resolution of less than 100 µm is obtainable. The detection rate is limited to about 10 kHz and can be increased up to 100 kHz with lower position resolution. This system has an intrinsic time resolution of about 1 nsec, which makes the investigation of fast processes possible.

The discharge was imaged on the detector through a pinhole (70-170 µm diameter), this very simple setup being free of optical aberrations. While keeping reasonable dimensions of the setup, a magnification of 20 is achievable. A smaller pinhole could allow for higher magnification but the image will be strongly affected by diffraction on the aperture and the number of incident photons on the detector will decrease.

Investigations have been performed in Ar at 0.25 bar with an array of 35 microdischarges without individual ballast. The electrical parameters are discharge current of 0.15 mA/hole and 250 V forward voltage. The detector has been operated in following conditions: +100 V applied voltage on the photocathode, MCP-front grounded, MCP-back at +2800 V and Ge layer at +3100 V.

The spatial distribution of the UV radiation emitted from the MSE sustained discharge is depicted in Fig. 2.

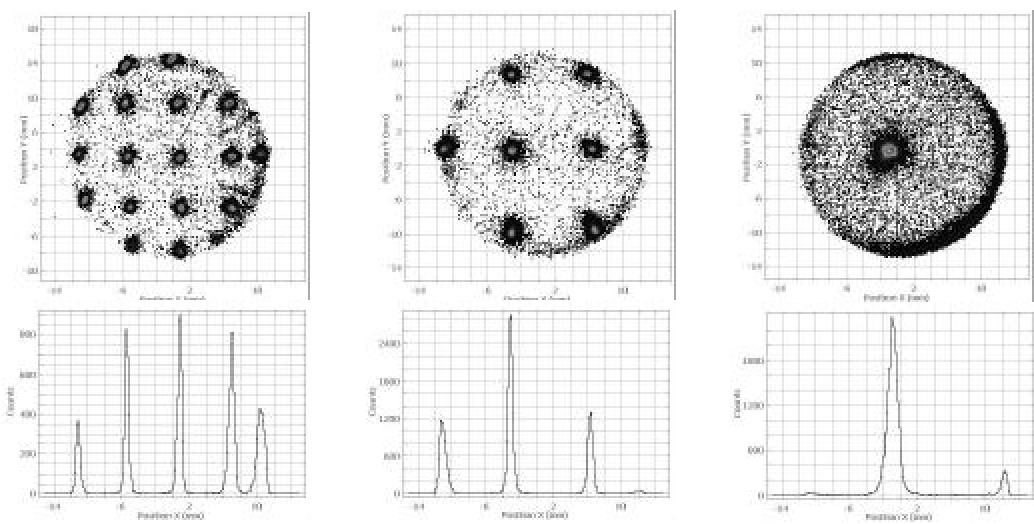

Fig. 2: UV emission by different magnifications: 2.1, 3.3 and 6.4.

The achieved magnification of the system allow for online analysis of the UV emission for single hole discharges or parallel operated discharges but is not high enough to make possible the investigation of the UV photon emission inside the discharge area. Due to the above mentioned limitations the pinhole geometry can not be extended to reach the needed magnification of about 100 and another setup based on UV optics has to used.

3 Conclusions

Both the optical appearance and the current-voltage characteristic are indicating a stable, non-filamentary glow discharge. Previous experiments have shown that the formative time of the discharge at low over voltages is around 1 µs, suggesting a space charge controlled Townsend discharge too.

In both diagnosis methods presented above the emitted radiation is not energetically resolved but if desired can be selected using narrow-band filters.

Until now no time resolved studies have been performed. The improvement of the system for higher magnification and time resolved measurements are envisaged. The ignition of the discharge, the transitions between different operation modes as well as the possible constriction of the discharge have to be investigated.

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