Electrical and optical characterization of microdischarges from DC up to 13,56 MHz in H_2, O_2 and water vapor

M. Klas[1], L.Moravský[1], M. Janda[2] and Š. Matejčík[1]

[1] *Department of Experimental Physics, Comenius University, Mlynská dolina F-2, 842 48 Bratislava, Slovakia*
[2] *Division of Environmental Physics, Comenius University, Mlynská dolina F-2, 842 48 Bratislava, Slovakia*

We present an experimental study of the atmospheric-pressure gas-breakdown phenomena in the hydrogen, oxygen gases and in water vapor microdischarges operated in the frequency range from DC up to 13.56 MHz. We have measured the electrical characteristics of the microdischarges, such as Paschen curves, and V-I waveforms, in the DC, kHz and RF frequency range. The microdischarges were studied at different experimental conditions (pressure range 15 to 700Torr and the electrode distances ranging from 2.5µm up to 2mm).

1. Introduction

The non-equilibrium atmospheric plasma sources operating in the glow mode are highly desired in many industrial applications, however, in the case of high pressure, the discharges tends to be constricted and easily transit to arcs [1-4]. In order to stabilize the high-pressure plasma and avoid the constrictions and arcing, one of the ways is to spatially confine the discharges to the dimensions below 1 mm [3]. Many phenomena occurring in microdischarges are still not clearly understood especially in case of RF discharges Thus the knowledge of the physical phenomena occurring in the microdischarges, are very important [5-7]. In this paper, we present experimental study of the atmospheric pressure gas breakdown phenomena in oxygen, hydrogen and water vapour discharges operated in the frequency range from DC to 13.56 MHz and for micrometer electrode gaps.

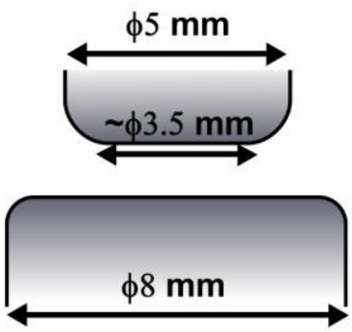

Figure 1: The Electrode system used in present experiment. The rounded edges eliminate the effects associated with the high electric field in the case of sharp edges.

2. Experimental setup

The two electrode discharge element consisted of bare molybdenum electrodes with dimension shown in Fig. 1. The discharge element was located in high vacuum chamber, pumped by turbomolecular pump. The detailed description of the apparatus can be found elsewhere [8].

The discharge was generated by supplying AC/DC power to the bottom electrode, while the top electrode was grounded. A current and voltage I-V probe was attached directly to the source, eliminating any cable connections, which might add inductance to the system. Probes were connected to an oscilloscope (Agilent DSO5032A) and calibrated with procedure to ensure accurate phase and power measurements [9]. Optical investigation of discharge were performed by a spectrometers OceanOptics SD2000(200–1100nm) and 2m monochromator Carl Zeiss Jena PGS2 coupled with an iCCD camera (Andor Istar). Images were taken by a camera (NikonD7100).

3. Results and discusion

In Fig, 2 we show the DC Paschen curves obtained for hydrogen, oxygen and water vapour at electrodes separation of 100µm. The general shape of low frequencies (100Hz -10kHz) Paschen curves agree well with those obtained for dc discharge. Breakdown process is basically the same as in case of static field due to short transit time of electrons cloud compare to the period of the field [10].

For the electric breakdown at higher frequencies, an important role plays the uniformity of the electric field. In the non-homogeneous electric field generated between electrodes with sharp edges we have observed a significant decrease of breakdown voltage compare to the DC and low frequency breakdown. In a homogenous field the effect was opposite. (HF breakdown voltage was increasing with frequency). We associate this behaviour with the effect of high electric fields generated in the region of the sharp edges. For this reason we have developed and used electrode system displayed in Fig. 1, which reduced the effect of sharp edges.

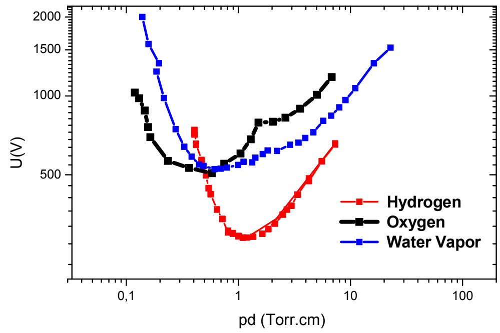

Figure 2: DC Paschen curve for Hydrogen, Oxygen and water vapour at electrode distance of 100 µm

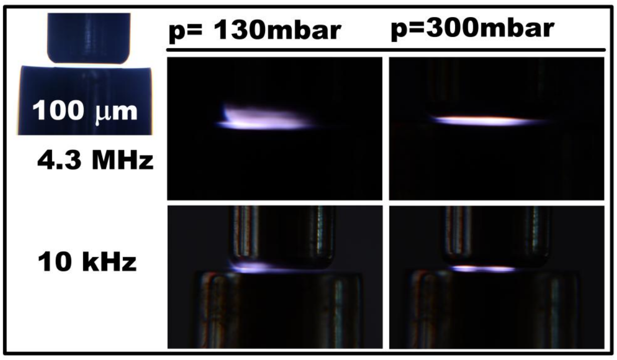

Figure 3: Images of hydrogen discharges at different condition of pressure and frequency (d=100µm)

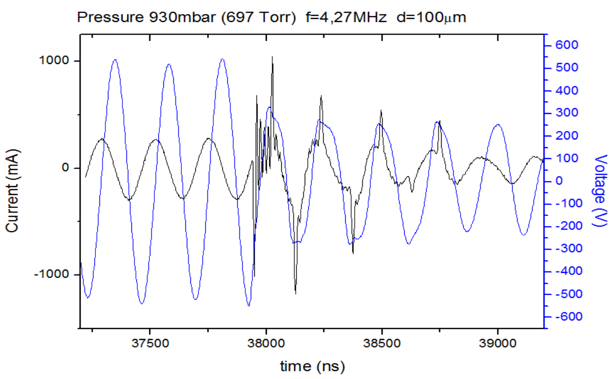

Figure 4: Hydrogen: V-I waveform at frequency of 4.3MHz and electrode distance of 100 µm and pressure 700Torr

In Fig 3 are shown images of hydrogen discharge for low(10kHz) and radio frequency(4.3MHz) at different pressure. In Fig. 4 are shown the current and voltage waveforms discharge generated for 100 µm electrode separation at 4,3MHz. The waveforms show the process of the discharge breakdown and afterwards the extinction of the discharge. Immediately after breakdown occurs, a ringing with a self-frequency of ~70MHz was observed due to the parasitic capacitance and inductance of the wires and probes. From I-V waveform it is clearly seen the distortion of the voltage after the first period due to formation of the space charge between the electrodes with a similar behaviour observed in low pressure glow discharges.

Acknowledgments

This research was supported by Slovak Research and Development Agency project APVV-0733-11

4. References

[1] Conrads H and Schmidt M. Plasma generation and plasma sources *Plasma Sources Sci. Technol.* **9** (2000) 441–54.

[2] Lieberman M A and Lichtenberg A J *Principles of Plasma Discharges and Materials Processing* (New York: Wiley) 1994

[3] Raizer Y P *Gas Discharge Physics* (Berlin: Springer) 1991

[4] L Schwaederl´e *et al J. Phys. D: Appl. Phys. 45* (2012)

[5] Y. P. Raizer, M. N. Shneider, and N. A. Yatsenko, *Radio-Frequency Capacitive Discharges* (CRC Press, Boca Raton, 1995).

[6] V. Lisovskiy, J. P. Booth, K. Landry, D. Douai, V. Cassagne, and V. Yegorenkov, *EPL (Europhys. Lett.)* **80**(2), (2007) 25001.

[7] J. L. Walsh, Y. T. Zhang, F. Iza, and M. G. Kong, Appl. Phys. Lett. **93**(22), (2008) 221505

[8] M. Klas, Š. Matejčik, B. Radjenović and M. Radmilović-Radjenović, *Phys. Plasmas 21*, 103503 2014

[9] Spiliopoulos, *Journal of Vacuum Science and Technology* A14, 2757 1996

[10] Llewellyn Jones, *Electrical discharge*, 1953