Operation of 13.56 MHz RF discharge in long gaps from sub-atmospheric to atmospheric pressure.

L. Li[1], A. Nikiforov[(*)1, 2], N. Britun[3], R. Snyders[3, 4], and C. Leys[1]

[1] *Department of Applied Physics, Research Unit Plasma Technology, Ghent University, Jozef Plateaustraat 22, Ghent B-9000, Belgium*
[2] *Institute of Solution Chemistry of the Russian Academy of Science, Academicheskaya St., 1, Ivanono, 153045, Russia*
[3] *Chimie des Interactions Plasma-Surface (ChIPS), CIRMAP, Universite de Mons, 20 Place du Parc, B-7000 Mons, Belgium*
[4] *Materia Nova Research Centre, Parc Initialis, B-7000 Mons, Belgium*
anton.nikiforov@ugent.be

In the present work RF plasma of 13.56 MHz generated in between two electrodes with a size of 50x50 mm at pressure range from sub-atmospheric to atmospheric is investigated. Plasma properties are studied by optical emission spectroscopy and absorption spectroscopy. The low pressure hollow cathode lamp is used to obtaine absolte densities of Ar^* metastable and resonance states $1s_3$, $1s_4$, $1s_5$, and $1s_2$. Plasma electron density and population of different Ar states are obtained as function of RF power density and gas pressures.

Nonthermal and low temperature plasmas are subject of a great interest in different fields of science and technology. Among others atmospheric pressure plasma jets, in particular, attract high attention because of their potential interest for different technologies, such as polymer treatment and biomedical applications [1,2]. In most of the plasma devices so called "coaxial configurations of electrodes" is used where the discharge is produced in a dielectric tube with a typical diameter of some mm. In practice, the spatial extension of the discharge is essential for applications and discharge generated in a long gaps of some cm is desired. Recent studies have focused on expansion of the number of plasma jets assembled in array so large area treatment can be achieved. Konesky G [3] used an array of 45 jets in order to achieve fast decontamination of the treated surfaces. Another way to produce long treatment area plasma is a generation of plasma in between the bare electrodes. M. Kong *et al.* [4] investigated RF plasma of Ar with 20 mm round electrodes and has found that stable and uniform discharge with gas temperature of 460-560 K can be sustained at pressure of 760 torr. In [5] a large gap RF discharge with one of the electrodes covered by dielectric has been generated in γ mode at atmospheric pressure in Ar as well as in N_2. Up to now very limited research on RF discharges with large electrodes at atmospheric pressure has been done and mostly optical emission spectroscopy and electrical measurements were used to characterized the discharge. Primary properties of long gap RF plasmas which are important in understanding of the discharge physics are electrons density, temperature of gas and electrons, and absolute density of species produced in the discharge.

In the present work RF discharge (13.56 MHz) is generated in between two electrodes of 50x50 mm size. One of the electrodes is covered by alumina ceramic of 250 μm thickness. The interelectrodes gap size is fixed for all experiments at 1 mm. Stabilization of the discharge is achieved by use of gas flow of Ar at 2 slm. The source is placed in a pumped chamber in order to investigate RF discharge in a range of working pressures from 300 mbar up to 1100 mbar and to avoid back diffusion of ambient air into the interelectrodes gap. The plasma properties are studied by means of emission spectroscopy which is used to determine electron density (N_e) and absorption spectroscopy which is used to estimate absolute density of Ar metastable states $1s_3$, $1s_4$, $1s_5$, and $1s_2$.

It was found that at low input power and pressure up to 500 mbar the discharge is filamentary with typical size of filaments of about some μm. The increase of the input power results in formation of uniform discharge in the whole interelectrodes gap. The absorption of light by plasma is used as simple and fast method to measure absolute densities of non-radiative states, e.g. metastable levels. The theory of the resonant absorption technique is discussed in details by Mitchell and Zemanski for a case of low pressure. This theory has been modified in the present work for higher pressure case where the Van-der-Waals broadening of lines start to be dominant. At high pressure of 300-1100 mbar range, Doppler and Van der Waals broadening contributions will determine the profile of absorption coefficient k_ν which can be well described by a Voigt function. The profile of absorption k_ν has been calculated, in the present work, from the theory and used together with absolute absorption coefficient to estimate the density of Ar metastables states as a function of the discharge power and pressure. The resulting absorption profile is presented in Fig.1 a) for one of the Ar transitions and is used to determine the absolute number density of $1s_5$ metastable level of Ar presented in Fig. 1 b).

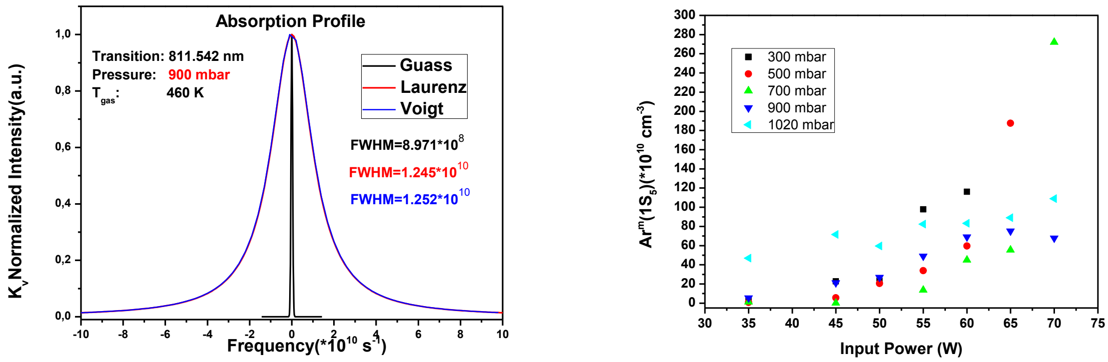

Fig. 1. Results of absorption spectroscopy of RF jet: a) calculated profile of Ar line corresponding to $1s_5$ state; b) absolute number density of $1s_5$ state measured by absorption spectroscopy.

The same method is used to determine population of other states of Ar at different pressures. It is found that population of $1s_5$ state is increasing with increase of the pressure which is in correlation with increase of electron density measured by OES techniques coupled with collision-radiative model. We found the increase of electron density in plasma from $1\text{x}10^{12}$ cm^{-3} to $5\text{x}10^{12}$ cm^{-3} with increase of the pressure from 300 to 1100 mbar. On the other hand the power at the range of 30-80 W has no pronounced effect on the electron density but strongly affects the population density of metastables. It is probably explained by expansion of the plasma with increase of the power which leads to higher density of metastables in the whole interelectrodes gap whereas the ionization degree of plasma and so electron density is less sensitive to increase of the power.

Finally, we found that developed plasma system can be interested for biomedical applications as a source of uniform plasma of a big size (50 mm) and can delivers high flux of metastables to treated surface so uniform treatment at short time is possible.

This work is supported by the China Scholarship Council (CSC), and N. B. is a postdoc researcher of the FNRS Belgium.

References

[1] S. Forster, C. Mohr, and W. Viol, *Surf. Coat. Technol*. **200** (2005) 827.
[2] M. Laroussi, W. Hynes, T. Akan, X. Lu, and C. Tendero, *IEEE Trans. Plasma Sci.* **36** (2008) 1298.
[3] X. Li, L. Dong, N. Zhao, Z. Yin, T. Fang, and L. Wang, *Appl. Phys. Lett.* **91** (2007) 161507.
[4] G. Konesky *Proc. SPIE* ,Sensing XI (2010) 7665
[5] B. Li, Q. Chen, and Z. W. Liu *Appl. Phys. Lett.* **96** (2010) 041502