Topic number: 10

Glow-like discharges in RF operated non-equilibrium atmospheric pressure plasma jets

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Meanwhile it is well established that non-equilibrium plasmas can be produced at atmospheric pressure by a variety of techniques; one of them makes use of atmospheric pressure glow discharges (APGDs) operated with radio-frequency (RF) [1]. Even in the absence of dielectric barriers uniform discharges can be sustained [2-10]. One application with great potential is the so-called atmospheric pressure plasma jet (APPJ) [1-2,4-5,8-10]. Usually the APPJ is operated with a gap spacing of 1 mm or even more. Hence, most investigations have been performed in this regime. Only recently narrow gaps have attracted some attention. However, a detailed investigation is still missing.

In the present study RF discharges were investigated in gap spacings ranging from 1 mm down to 0,1 mm in 0,1 mm steps. Two APPJs with different size were studied; the electrode area of device APPJ3 has half the electrode surface of device APPJ2. However, both exhibit a sandwich structure as shown in Fig. 1. Electrodes were made of stainless steel. The experiments were performed using pure helium as process gas at ambient conditions. An excitation frequency of 13,56 MHz was used for the RF power. The electrical properties of the discharges were determined using a digital oscilloscope, a high voltage and a current probe, all with high bandwidth. The discharge pattern between the electrodes was investigated using a conventional digital camera. The time evolution of the discharge pattern was studied using a synchronized image-intensified CCD camera with nanosecond time resolution.

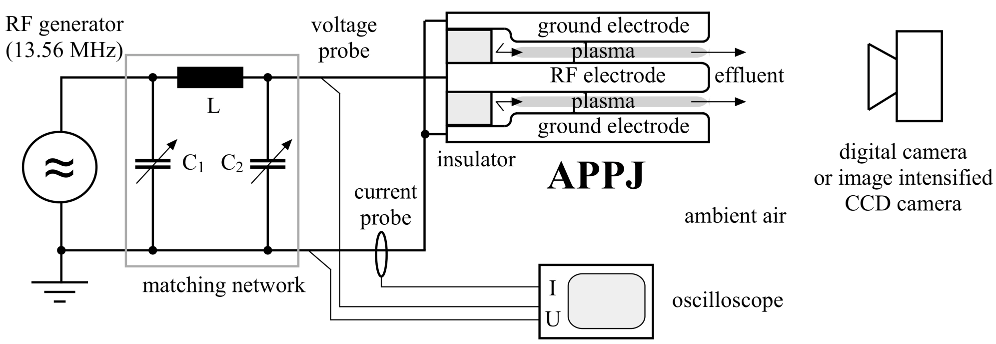

Fig. 1: Illustration of the experimental set-up.

It turned out that uniform discharges can be realized in the entire range of gap spacings investigated. The so-called alpha discharge can be clearly identified in larger gap spacings, whereby two regimes exist, a normal regime with partial coverage of the electrodes and an abnormal regime with increasing discharge intensity. At higher RF powers an ignition of a gamma discharge occurs leading to a highly non-uniform discharge. With decreasing gap spacing not only the bulk region of the alpha discharge gets thinner, but also the normal regime becomes narrower. At 0,4 mm no partial coverage of the electrodes and hence no normal regime was observed anymore. However, the uniform abnormal discharge could be sustained down to gap spacings of 0,1 mm.

By doubling the electrode area from 36 cm^2 (APPJ3) to 72 cm^2 (APPJ2) the discharge current doubles as well, whereby the current-voltage-characteristics is similar, as can be seen in Fig.2. For clarity only a subset of I-V-curves is exhibited. Note, the discharge currents were derived from the measurements by taking into account the displacement current due to the stray capacitance [2,9]. This means that the current density is roughly the same for the same discharge voltage in both devices. There are however two remarkable differences. First, with decreasing gap spacing the voltage needed to sustain a certain current density increases faster than expected. Second, it is not possible to double the dissipated RF power by doubling the discharge area. Surprisingly, it turned out that in the larger APPJ only a little bit more RF power can be dissipated before an ignition of the gamma discharge takes place. This is actually bad news, as it limits the possibility to up-scale such plasma sources.

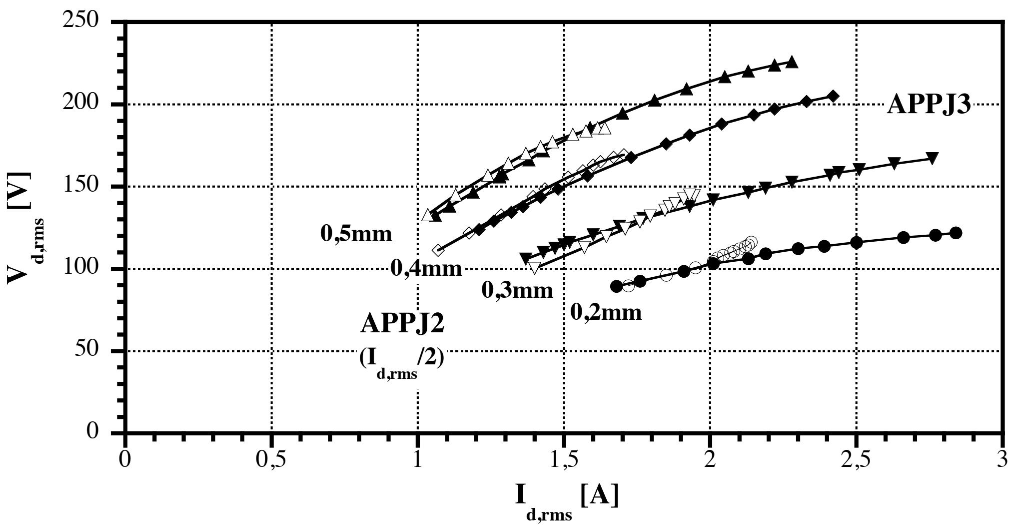

Fig. 2: I-V- characteristics of two APPJs of different discharge area
(open symbols APPJ2 72 cm^2, full symbols APPJ3 36 cm^2) and gap spacings (0,2 - 05 mm).
For better comparison discharge current of APPJ2 is divided by 2.

Reference

[1] J. Laimer and H. Störi, 2007 *Plasma Process. Polym.* **4** 266
[2] J. Laimer and H. Störi, 2006 *Plasma Process. Polym.* **3** 573
[3] S.Y. Moon, J.K. Rhee, D.B. Kim and W. Choe, 2006 *Phys. Plasmas* **13** 033502
[4] J. Laimer, A. Puchhammer and H. Störi, 2009 *Plasma Process. Polym.* **6** S253
[5] J. Laimer, H. Reicher and H. Störi, 2009 *Vacuum* **84** 104
[6] D.W. Liu, F. Iza and M.G. Kong, 2009 *Plasma Process. Polym.* **6** 446
[7] D.W. Liu, F. Iza and M.G. Kong, 2009 *Appl. Phys. Lett.* **95** 031501
[8] J. Laimer, S. Haslinger, W. Meissl, J. Hell and H. Störi, 2005 *Vacuum* **79** 209
[9] S. Haslinger, J. Laimer and H. Störi, 2007 *Vacuum* **82** 142
[10] J. Laimer, S. Haslinger and H. Störi, 2007 *Plasma Process. Polym.* **4** S487