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Investigation of an atmospheric pressure radio-frequency capacitive plasma jet

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Abstract

We have constructed a large area atmospheric pressure plasma jet (LAAPPJ) composed of two planar electrodes with an area $38\,cm^2$ at a distance of 2.5 mm.The LAAPPJ was operated with helium at a gas flow rate of 1.5 mmol/s. The electrical properties of the discharge were studied by measuring the voltage and the discharge current simultaneously using a high voltage probe, a current probe and a digital oscilloscope. Pictures of the discharge were taken with a digital camera.

Two discharge modes can be sustained within certain limits. At RF input powers of 50–420 W an α-discharge can be sustained, however, below approximately 300 W the electrodes are only partially covered with the glow. At higher powers a breakdown occurs and a transition to a γ-discharge takes place, whereby the α-discharge dies out. The γ-discharge only covers a part of the electrodes and can be sustained down to powers of 50 W. Below this power the discharge extinguishes.

Keywords: APPJ; Helium; RF discharge; α-discharge; γ-discharge

1. Introduction

Usually plasma sources operated at atmospheric pressure are based on arc discharges and produce thermal plasmas with temperatures well above a few thousand K. At reduced pressures large area discharges can be easily sustained in the glow discharge mode. However, large area glow discharges at atmospheric pressure were considered to be rather unstable. Recently, it was reported that an atmospheric pressure plasma jet (APPJ) can be generated in a capacitive radio-frequency (RF) plasma source, resulting in a stable glow-like discharge with a rather low gas kinetic temperature [1–6]. However, still many of the experiments have been performed well below 10^5 Pa, either accomplished in a vacuum chamber or at ambient pressure at higher altitude.

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2. Experimental details

A schematic of the experimental setup is shown in Fig. 1 illustrating the electrical circuit for the large area atmospheric pressure plasma jet (LAAPPJ). The discharge used for this study is produced between two planar electrodes made of copper; one is RF powered and the other one is grounded. The effective surface area of the electrodes is approximately 38 cm^2. The construction allows a variation of the gap spacing between 0.5 and 2.5 mm using insulating PTFE spacers; a gap spacing of 2.5 mm is used throughout the experiments. In the real setup the powered RF electrode (in the centre) is surrounded by grounded electrodes and separated from them by PTFE insulators leaving only the spacing for the discharge open. Of course, due to the shielding of the powered electrode this setup has a higher capacitance as Fig. 1 would suggest. Therefore, there is a parasitic capacitance in parallel to the plasma. The LAAPPJ is operated with helium at a gas flow rate of 1.5 mmol/s. Helium is of unknown purity. Helium is injected through both side walls close to the back side PTFE insulator of the LAAPPJ, where the gap between RF and grounded electrode is much larger. After flowing through the narrow gap spacing, where the discharge in maintained, helium is exhausted into the ambient air. The atmospheric pressure at the altitude of Vienna is in average about 960 hPa. As Park et al.[3] have shown that an impurity level below 0.1% does not alter the electric properties of the discharge very much, back diffusion should not be a problem. Both, the RF powered electrode and the grounded electrode are water cooled and are connected in series by hoses, each having a length of over 0.8 m.

The discharge is operated at a frequency of 13.56 MHz using an impedance matching network. Forward as well as reflected power is measured. Additionally, the voltage across the discharge and the current are measured simultaneously using a high voltage probe (Tektronix P5100 with a bandwidth of 250 MHz), a current probe (Tektronix P6021 AC with a bandwidth of 60 MHz) and a digital oscilloscope (Tektronix TDS 3052B with a bandwidth of 500 MHz). The accuracy of this setup was tested with a vacuum 100 pF capacitor. Measurements with forward RF powers of up to 200 W revealed sinusoidal waveforms for both current and voltage, whereby the current leads the voltage by $90 \pm 3^{\circ}$. The ratio of voltage to current revealed a capacitance of 109.7 pF. Considering parasitic capacitance the measurements are sufficiently accurate.

Additionally, the discharge gap is observed in order to investigate the discharge pattern between the electrodes. The front side of the LAAPPJ is illuminated with a 500 W halogen lamp. Pictures showing the entire front side are taken directly with a digital camera (Minolta Dimage Xt).

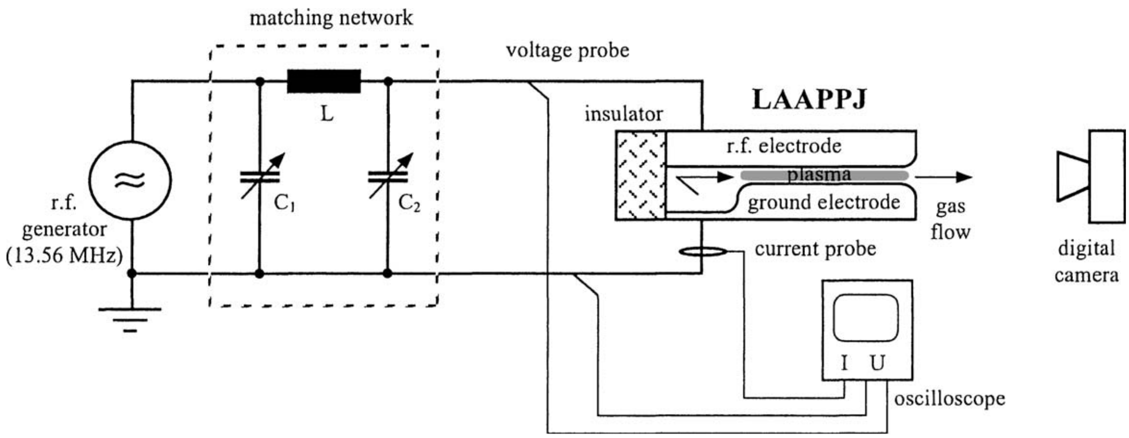

Fig. 1. Schematic illustration of the experimental setup of the LAAPPJ.