Current-voltage characteristics of a RF plasma jet discharge with bare electrodes at low and atmospheric pressure

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We have investigated the I-V characteristics of a RF plasma jet generated in flowing argon by a discharge with bare electrodes in parallel plate-nozzle configuration, at various pressure values from 10 mbar to 1000 mbar. The discharge regimes are discussed for the two limits of the investigated pressure domain, with respect to the non-equilibrium character of the generated plasma.

Introduction

Electrical measurements of the plasma sources may give relevant information on the discharge regimes. In this contribution we investigate the regimes of a plasma jet discharge, generated in argon by a parallel plate - nozzle configuration supplied with radiofrequency power. This kind of discharge was previously reported as being the basis of expanding plasma sources [1, 2] used in various applications like nanostructured carbon deposition, cleaning, and surface modification.

Experimental

Figure 1 shows a schematic view of discharge configuration and measurement setup. Plasma is generated in the interelectrodic gap (1.5 mm) and expands through the nozzle (1.8 mm diameter) as a jet. The jet develops in a quartz tube which was connected to the vacuum system. Both electrodes were water cooled. The discharge was fed with argon at constant flow rate of 3000 sccm. The pressure values, measured in expansion, were fixed at predetermined values in the range 10-1000 mbar by controlling the suction rate of the pumps. The discharge was powered by a RF generator (13.56 MHz) through an impedance matching network. The current and voltage probes (P6021 & P6015A, Tektronix) were connected close to the discharge. Signals collected by probes were acquired by a digital storage oscilloscope. The RF generator and oscilloscope were controlled by dedicated software which allows controlled incrementation (decrementation) of the forwarded power (range 0-150 W, steps of 2 W), with simultaneous recording of current and voltage waveforms. The data (current, voltage, phase shift) were analysed in the frame of a simplified electrical model: the electrode configuration without plasma is represented by a capacitor, which is connected in parallel with a series RC circuit; here R represents the plasma resistance and C the capacitance of the sheaths. Furthermore, the electrical parameters of discharge (resistance, impedance, real current, voltage, active and reactive power) were determined by processing the waveforms and their phase shift.

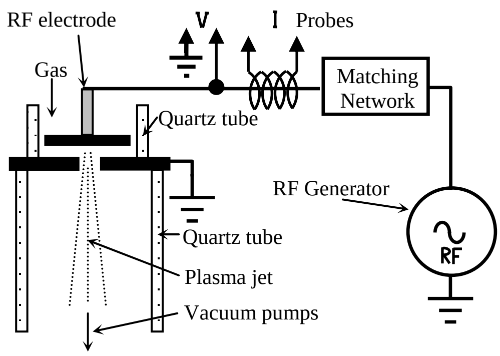

Fig. 1: Schematic view of discharge configuration and measurement setup.

Results

Figure 2 and Figure 3 show two electrical characteristics of the described discharge system. They correspond to low (10 mbar) and atmospheric pressure. In these figures the *x* axis represents the real current (I_p) through discharge and the *y* axis the applied voltage (U). Each point in graphs corresponds to a different forwarded power value. The following zones are distinguished: AB – absence of discharge, B –breakdown point, B-C transition to discharge state, C-D discharge characteristic when power increases, D- turning point for the power, D-E discharge characteristic when power decreases, E extinction point, E-A absence of discharge. The curves present the well-known hysteresis behaviour, with values of extinction power (and voltage) much lower than the breakdown values. Such curves, obtained for different pressures, can be used to infer some of the discharge properties. We exemplify this in Figure 4, where the dependence of the voltage of the B point versus pressure is shown: it represents a breakdown-like curve for the system, apparently exhibiting two shallow minima.

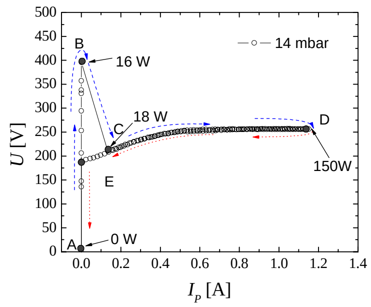

Fig. 2: I-V characteristic curve at 14 mbar.

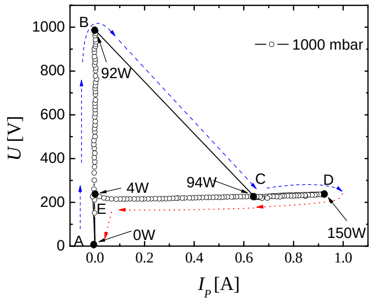

Fig. 3: I-V characteristic curve at 1000 mbar.

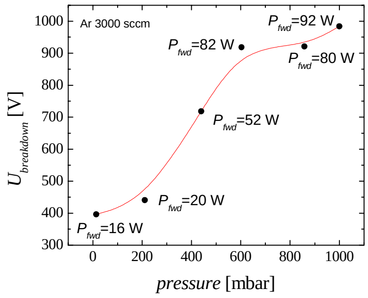

Fig. 4: Dependence of breakdown voltage upon pressure.

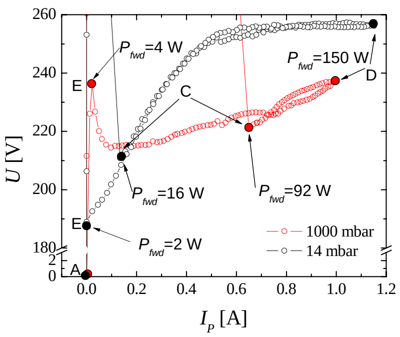

Fig. 5: Details of I-V characteristic curves at 14 mbar and 1000 mbar.

One of the important questions, frequent when operating atmospheric plasmas, regards the discharge regime at high powers. A detail of the behaviour of the I-V curves at high powers is presented in Figure 5. The characteristics have a positive slope, in spite of the fact that an arc regime is expectable in this region. The results suggest an abnormal or pre-arc regime; thus a non-thermal plasma jet is produced, even the power values are high.

An interesting aspect can be observed in the low power range, also represented in Figure 5. The atmospheric pressure characteristic, recorded during power decrement, presents a negative slope before the extinction point: this indicates a subnormal glow regime. Imaging studies applied to the discharge in the interelectrodic gap (not shown here) showed that a diffuse glow is filling the gap, but coexisting with a column of contracted more intense plasma. Presumably, the glow represents a RF α discharge, and the column a γ discharge. The plasma column gradually disappears by power decreasing (Figure 6), only the glow persisting at the low power limit. Thus a transition from γ to α discharge forms is first noticed; afterwards, by further decrease of power the α discharge is pushed towards the Townsend regime.

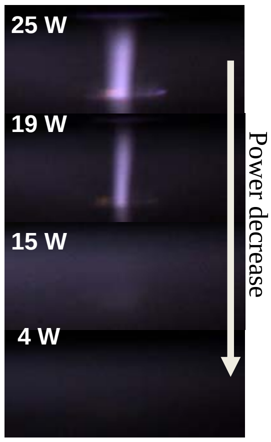

Fig. 6: Images of the interelectrodic space at decreasing power values.

Conclusion

The I-V characteristics of the RF plasma jet discharge in parallel plate-nozzle configuration, in flowing argon at 3000 sccm, indicate that a nonthermal plasma character can be maintained at atmospheric and low pressure even for high powers, as of 150 W. The discharge is in a pre-arc regime. We explain this behaviour by the efficient cooling of electrodes, and the using of high gas flow rates. At low power, a subnormal glow regime is noticed in case of atmospheric pressure jet discharge.

Acknowledgments

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References

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