Analysis of the stability and behavior of cold atmospheric pressure microplasma jets in argon

J. Benedikt, B. Barwe, Coupled Plasma-Solid State Systems, Ruhr-University Bochum, Germany (July 2012)

Application Note

Introduction

Non-equilibrium plasmas are known to be an effective source of excitation and reactive species. Their non-equilibrium character with hot electrons with kinetic energy in the range of few electron volts and cold atoms or molecules is an important feature.

The non-equilibrium plasmas are easily generated under low pressure conditions, where the mean free path of electrons is large and diffusion fast. The non-equilibrium conditions in plasma can be, however, generated also under atmospheric pressure conditions, cold atmospheric pressure plasma (CAP) is formed. It has several advantages. In ideal case, no vacuum pumps are needed, continuous treatment of substrates in roll-to-roll technology is possible, and vacuum sensitive objects, even living tissues such as human skin, can be treated. One way to generate CAP is to reduce the plasma dimensions to sub millimeter size. When combined with the high gas flows, microplasma jets with high power densities, high electric fields and effective gas cooling are obtained.

In this report, two examples of microplasma jets operated in argon gas will be introduced. The first jet is a DC driven discharge located at the tip of a narrow capillary, the second uses a MHz frequencies to generate a long plasma filament in a glass tube.

Experimental setups and diagnostics

Fig. 1 shows detailed scheme and the photograph of the DC jet during operation. It is a slightly modified version of the jet reported by Sankaran et al.[1] The source consists of a negatively biased capillary with inner diameter of 180 μm, which is facing on axis a one-mm diameter orifice in the grounded electrode. Argon gas is used as a plasma forming gas. The plasma is inside the glass tube, which maintains the controlled gas atmosphere. Silicon nanocrystals are formed when few ppm of SiH_4 are admixed into argon. Additional gas flow through the glass tube is used to accelerate the transport of plasma generated nanoparticles through the grounded electrode and to cool the capillary tube.

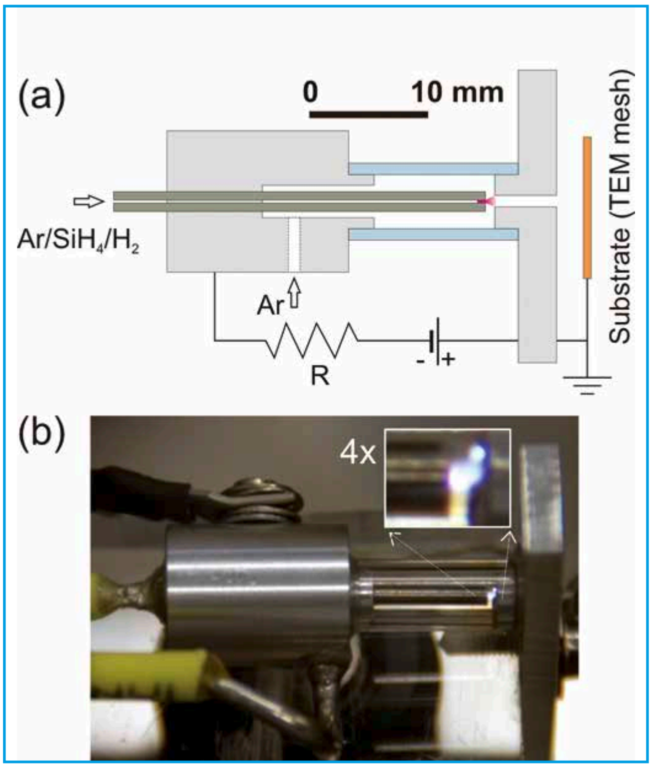

Figure 1: Schematic of the DC hollow cathode microplasma jet reactor (a) and its photograph with plasma (see the enlarged inset) generated in argon gas (b).

Here, the EMCCD camera Luca-R-UV 604 in combination with the InfiniProbe S-80 UV long distance microscope is used to image the plasma emission at the tip of the capillary. Fig. 2 shows 4 photographs of the jet observed axially through the anode (the camera with the objective is at the position of the substrate in Fig. 1a). The image in the upper left corner was captured without the plasma. The 180 micrometers inner diameter is clearly visible through the one millimeter diameter hole in the anode. The other three images show snapshots of the Ar plasma (exposure time 0.01 ms, without EM amplification). These photographs clearly show that the plasma is not located inside the hollow cathode but it has a form of short moving filaments connecting the cathode with the anode. The unstable position of the filaments can significantly lower the efficiency of the nanoparticle formation and can lead to broader particle size distribution, because the residence time of precursor gas in the plasma and the plasma density vary with time.

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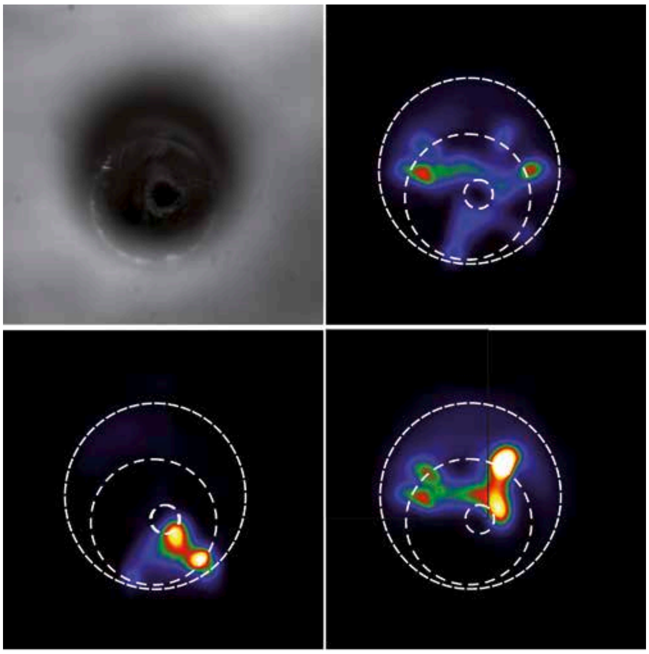

Figure 2: Images of the DC Microplasma jet in argon captured through the hole in the anode. Left upper corner: plasma not running. Other images: Plasma current 5 mA, Argon flows: capillary 100 sccm, side 1400 sccm.

Contraction of plasma into filaments, when operated at atmospheric pressure, is typical for argon gas. This is demonstrated in Fig. 3, where 4.52 MHz sinusoidal voltage is applied between a pin electrode inside a glass tube and a movable cylindrical electrode (grounded) located outside on the glass tube. A narrow slit is formed in this electrode to allow the observation of the plasma in the region behind the electrode, see Fig. 3a). Argon plasma can be generated in the glass tube between the pin electrode and outer electrode and beyond, as shown in Fig. 3b)-d), where the effect of gas flow variation is demonstrated. Again, the pictures have been captured with the same combination of Luca-R camera and Infinity long distance microscope (exposure time 0.8 ms, no EM amplification necessary).

The plasma exists in form of filaments with diameter between 100 and 200 micrometers as confirmed in another measurement of argon plasma under similar conditions [2]. The selected gas flow has a dramatic effect on the stability of the filament position and on the maximum filament length. The filament is localized at one position, the plasma can be operated at electrode distance larger than 10 mm and the plasma extends beyond the grounded electrode at argon gas flows smaller than 1 slm. The gas temperature significantly increases under these conditions. The filaments start to change their position as the gas flow is increased. Additionally, the distance between both electrodes has to be reduced to sustain the plasma. To bare eyes the plasma appears homogeneous and filling completely the glass tube.

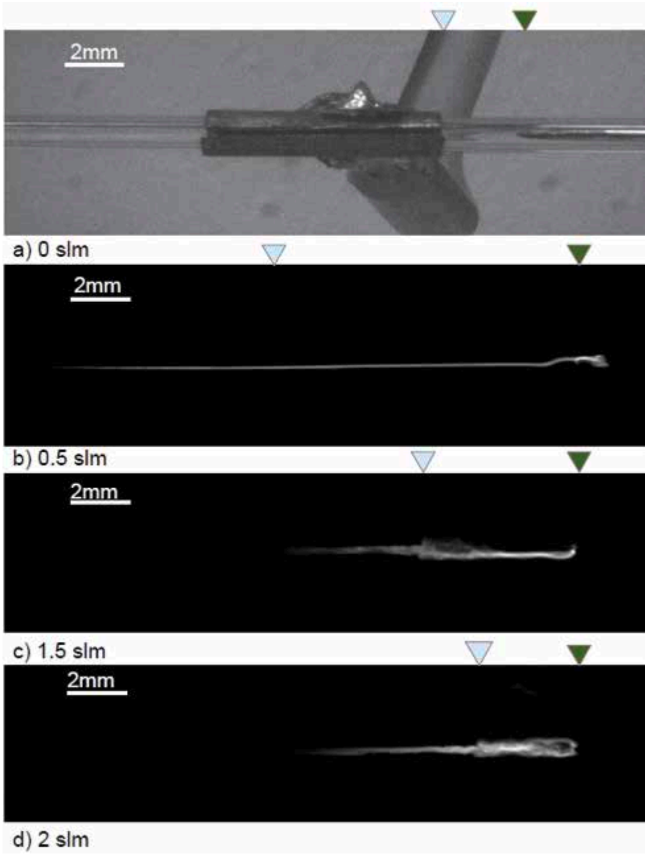

Fig. 3: Atmospheric pressure microplasma jet operated with 4.52 MHz in argon. A) Photograph of the jet without the plasma. b)-d) appearance of the jet with different argon gas flows. The green and blue triangles indicate the position of the pin end and edge of the grounded electrode respectively.

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These measurements indicate that the gas flow has a strong influence on the stability of the filament position and on the gas heating.

Summary
The Luca-R-UV is a versatile EMCCD camera, which can be effectively used for imaging of microplasma discharges. The EM amplification was not necessary up to know. However, the EM amplification will be used during a measurement of spatial distribution of very weak emission line of atomic Si (251.6 nm) with 250 nm filter in front of the camera. Longer integration times are necessary for these measurements and, therefore, the position of the plasma filament has to be stabilized first. The measurement at this UV wavelength is possible because our special UV-sensitive Luca-R employs a quartz instead of a glass window in front of the EMCCD sensor.

References

[1] R. M. Sankaran, D. Holunga, R. C. Flagan, K. P. Giapis, Nano Lett. 5 (2005) 537

[2] B. Niermann, R. Reuter, T. Kuschel, J. Benedikt, M. Böke and J. Winter, Plasma Sources Sci. Technol. 21 (2012) 034002

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