Topic number: 5

EXPERIMENTAL INVESTIGATION OF THE ELECTRON DENSITY OF A PLASMA JET IN SELF-ORGANIZED DISCHARGE REGIME

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Miniaturized plasma jets represent an emerging technique for surface treatment at ambient atmosphere. Applications include surface cleaning, surface activation, film deposition and the reduction of micro-organisms. The particular plasma source under study here is a capacitively coupled non thermal capillary jet (27.2 MHz) with two outer ring electrodes around a quartz capillary between which a gas (Ar) flows at rates about 1 slm. The plasma source is operated in so-called locked mode, which is a kind of self-organized discharge regime of this plasma source [1]. Downstream the active discharge region another compound (i.e. thin film producing agent) can be added in small quantities (fig. 1). An enhanced quality of films deposited in locked mode as compared with a plasma jet consisting of stochastic, irregular discharge filaments was reported previously [2]. The aim of the study is the investigation of physical causes, which determine the appearance of the locked mode and ultimately the advantageous film properties. The scope of the present work is the experimental investigation of the electron density maintained in the active discharge region between the electrodes of the plasma jet. Optical emission spectroscopy (OES) has been carried out by means of a 0.5 m spectrometer (Acton Spectra Pro 2500i) with a grating of 2400 g/mm. An iCCD camera (PI Max, Princeton Instruments, 1024×1024 pixel) at the exit port of the monochromator served as detector. The width of the entrance slit is adjusted on 30 μm to optimize the signal at a spectral resolution of 29 pm. The optical system collects the emission of the plasma with a spatial resolution of 1 mm.

For the optical measurements, the small amount of OH groups and H atoms produced in the plasma under presence of ambient air containing residual water vapour is utilized. Practically, a humidity of 20 – 30% is sufficient for the diagnostics of an atmospheric pressure argon plasma in an open flow regime. In this study, the spectroscopy of the H_β of the Balmer series (2p-4d transition, 486.128 nm) and OH rotational lines of the Q1 branch (A: 307.844 nm, B: 307.995 nm, C: 308.328 nm, D: 308.520 nm, fig. 2) have been used for the quantification of the Stark spectral line broadening and the rotational temperature, respectively.

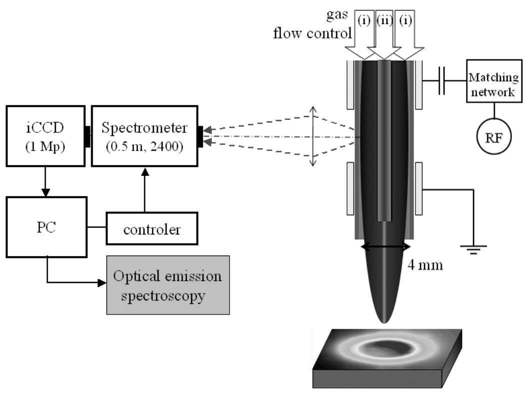

Fig. 1: Schematic drawing of the experimental set-up illustrating the spectroscopic arrangement focused to the active discharge zone while the plasma source is directed to a flat substrate for stationary film deposition

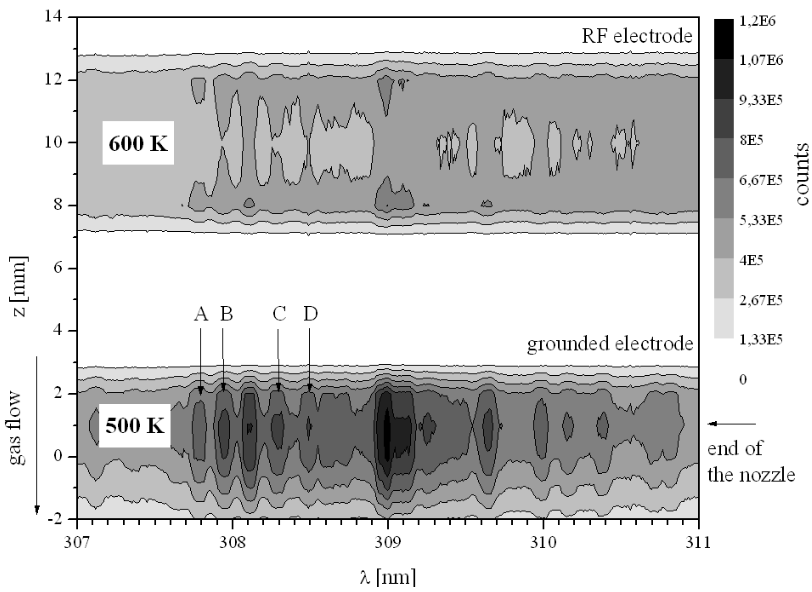

Fig. 2: OES in OH region along the jet axis. A, B, C, and D denote evaluated rotational lines of OH, the resulting rotational temperature is calculated for both regions, active discharge region and effluent plasma plume.

The calculation of Stark broadening is based on the consecutive separation of the influence of the other relevant broadening mechanisms [3, 4] from the measured line profile. The instrumental broadening (32 nm) was obtained experimentally by use of a thulium hollow cathode lamp. The resulting Doppler broadening is 9 pm, as calculated for a neutral gas temperature of 600 K. This temperature was obtained as an approximation resulting from the evaluation of the OH rotational temperature based on the Boltzmann plot method [6]. The correlation coefficient of the related calculation remained above 0.98. The resulting Stark broadening is 52 pm.

According to the GKS theory, the Stark broadening of H_β allows to obtain the electron density in the plasma for a large range of electron temperatures [5]. In our case, the electron density ranges between $8.0 \cdot 10^{13}$ and $2.0 \cdot 10^{14}$ cm^{-3}. This value is near to the upper limit, which was assumed in our previous hypothesis [1]. In comparison to other atmospheric plasma sources [7, 8], the higher electron density can be supported by enhanced electric field homogeneity in tightly closed discharge arrangement of the locked mode and thus would favor the effective application of the self-organized discharge mode.

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