Gas flow velocity in the low pressure hollow cathode plasma jet sputtering system

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Results from two independent measurements of flow velocity from the plasma jet nozzle outlet are presented. Operation of the discharge in the pulse regime enabled to detect the delay of the positive ion signal to the negatively biased Langmuir probe. In the negligible electric field below the nozzle the ions moved with neutral stream which allowed to calculate the flow velocity from the measured delay. As the second method the Pitot tube was used. It was shown that the flow velocity is almost unaffected by the presence of plasma. Results of both metods are in a good correspondence. It was documented that the hollow cathode discharge can be operated in both subsonic and supersonic regime.

The hollow cathode plasma jet sputtering system is used in deposition of a broad scale of materials. As examples TiO_2 [1], TiN [2], AlN, CrN [3], $LiCoO_x$, ZnO or $SrTiO_3$ (STO) and $Ba_xSr_{1-x}TiO_3$ (BSTO) ceramics can be mentioned. The system utilizes the formation of the plasma jet channel which makes it convenient for the local treatment and substrates with non flat e.g. hollow shape. Since the particles sputtered from the hollow cathode are carried to the substrate by the stream of working gas, which is typicaly argon, the plasma channel structure has considerable influence on the deposition process. Its fundamental parameter is the flow velocity between the nozzle and the substrate. This phenomenon was studied in [4] on the rf plasma jet at higher gas flow up to several hundreds of sccm by digital processing of the discharge photographs.

In this contribution the measurement of the flow velocity along the plasma jet axis in the range of the working pressures 1 to 100 Pa commonly used in the system at the fixed gas flow is presented. The experimental system is depicted in Fig. 1. The water cooled nozzle made from titanium serves as cathode and via the linear motion feedthrough is inserted from top into cylindrical UHV chamber pumped by oil-free pumping system. The dc pulsed mode discharge operation is achieved by IGBT switch powered by the battery of capacitors charged from the continuous dc power supply. To keep the onset regular and the discharge stable a weak continuous discharge was maintained also during the off time by the resistor parallel to the switch. For more details about the system see [5].

The operation of the plasma jet discharge in the pulsed regime with short pulses is an advantage for the determination of the plasma flow. Under the assumption that the ionization of the working gas takes place mainly inside the plasma jet nozzle during the pulse on-time and if there is no electric field outside the nozzle, the ions are carried by the neutral gas stream and spread by the diffusion process. From the maxima of the ion current to the probe positioned at different positions below the nozzle the spatial course of the ions velocity can be computed, see Fig. 2.

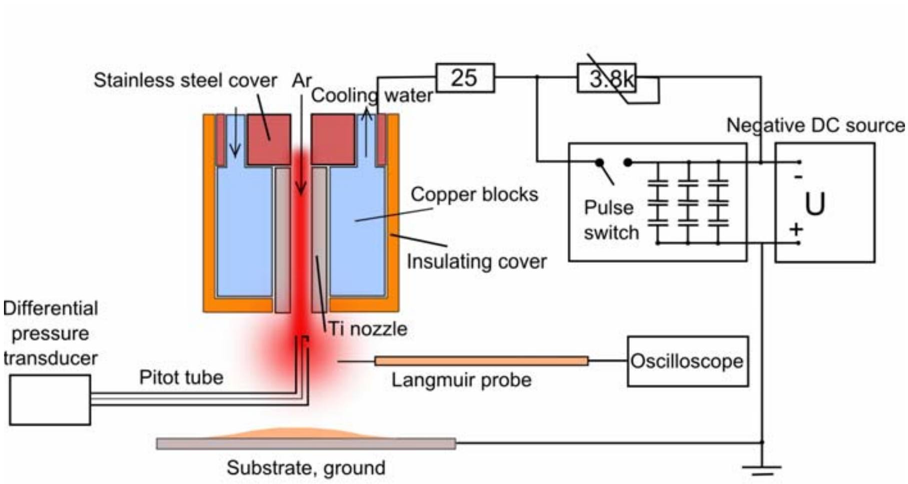

Fig. 1. Scheme of the low pressure hollow cathode plasma jet sputtering system with the Pitot tube and Langmuir probe used for the flow velocity measurements and the power supply circuit for the pulse excitation of the dicharge.

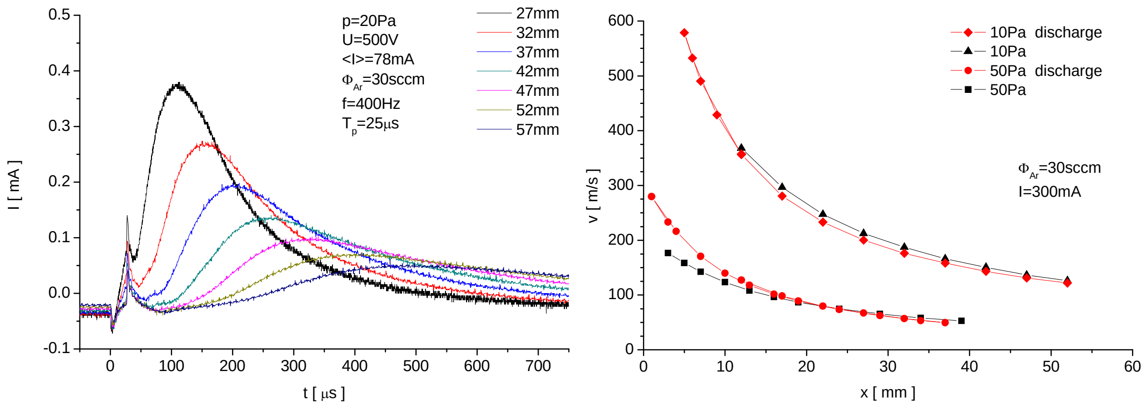

Fig. 2. Left graph: Typical course of the ion current to the negatively biased probe for different distances between the probe and the nozzle. Right graph: Comparison of results obtained from Pitot tube measurements on dependence whether the discharge is on or off.

The discharge in the pulsed regime was operated under these parameters: negative voltage during on-time $U = 500$ V, repetition frequency $f = 400$ Hz and the duration of the pulse $T_p = 25$ μs. The instantaneous discharge current reached the maximal value of $I \sim 3$A.

The independent method to measure the neutral gas velocity is the Pitot tube [6]. Its applicability has been already proved in a broad scale of experiments so it can be considered as a standard tool for the flow velocity determination [7]. The Pitot tube for presented measurements was constructed from a couple of stainless steel tubes with outer diameter of 1.2 mm guided side-by-side. One of the tubes had the inlet oriented in the flow direction whereas the second one was at the end closed and the inlet was drilled in the wall, see Fig. 1. The pressure difference was measured by means of a differential pressure transducer with the full scale range of 0.2 Torr. Pitot tube measurements with the discharge being on and off are compared, see. Fig. 2. The deviation is observed just near the nozzle outlet and at higher pressures when the Pitot tube considerably affects the discharge behaviour. No difference further from the nozzle shows that the most of the heat delivered from the power supply is absorbed into the cooling media.

The measurements of the flow velocity from the plasma jet by means of two independent experimental methods were compared. The first method was based on the measurement of the positive ions time of flight to a negatively biased Langmuir probe, the second method was the use of the Pitot tube. The results obtained by these two methods are in good correspondence. The plasma jet can be operated as in subsonic as in supersonic regime. The course of the flow velocity in the plasma jet axis was measured in dependence on the distance from the nozzle outlet, on the pressure in the reactor chamber and on the flow of the working gas as well.

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