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THE EFFICIENCY OF A FOCUSING SYSTEM WHEN ION CURRENT TRANSPORTING TO THE DIFFERENTIAL PUMPING SYSTEM OF A MASS SPECTROMETER

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Abstract. In this work, a charge particle beam transport in a corona discharge ion source with a thin diaphragm focusing system taking into account the gas-dynamic flow in the vicinity of the nozzle has been studied experimentally. The space of influence of the gas-dynamic flow on the ion transport in the vicinity of the nozzle was shown not to exceed two nozzle diameters. The results of comparing the efficiency of the ion beam transport in the ion source with using the focusing system and without it are presented. Using the focusing system allowed one to triple the current entering the collector and to raise the sum of currents entering the nozzle and collector by an order of magnitude.

Keywords: ion source, mass spectrometer, differential pumping system, focusing system, ion transport

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ЭФФЕКТИВНОСТЬ ФОКУСИРУЮЩЕЙ СИСТЕМЫ ПРИ ТРАНСПОРТИРОВКЕ ИОННОГО ТОКА В СИСТЕМУ ДИФФЕРЕНЦИАЛЬНОЙ ОТКАЧКИ МАСС-СПЕКТРОМЕТРА

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Аннотация. Проведено экспериментальное исследование транспортировки заряженных частиц в ионном источнике с коронным разрядом и фокусирующей системой, состоящей из тонких диафрагм, с учетом газодинамического течения в окрестности сопла. Показано, что область влияния газодинамического течения на транспортировку ионов в окрестности сопла не превышает двух диаметров сопла.

Представлены результаты сравнения эффективности транспортировки ионного пучка в ионном источнике с фокусирующей системой и без нее. Использование фокусирующей системы позволяет втрое увеличить ток на коллекторе и на порядок величины повысить сумму токов, приходящих на сопло и коллектор.

Ключевые слова: ионный источник, масс-спектрометр, система дифференциальной откачки, фокусирующая система, транспортировка ионов

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Introduction

Atmospheric-pressure ion sources have long been used in various types of mass spectrometers to solve a diverse range of problems in proteomics, bioorganic chemistry, ecology, criminology, etc. [1–3]. The main common disadvantage of such sources are the significant (two orders of magnitude of the total source current or higher) transmission losses of the ion beam during transport from the ionized region with atmospheric pressure through the nozzle to the first stage of the differential pumping system (DPS) of the gas dynamic interface of the mass spectrometer [4]. Current attempts to increase the ion beam transmission revealed it is necessary to achieve electrostatic focusing of ions on the nozzle [5–9].

Earlier numerical and experimental studies [10] considered a promising focusing system of thin apertures [11] in a corona-discharge ion source in stagnant gas; the system proved to be highly efficient, with the correct approach to choosing its geometry. However, ion transport in real ion sources with atmospheric-pressure ionization is influenced not only by the electrostatic field, but also by the gas-dynamic flow of neutral gas in the vicinity of the nozzle (gas flow into the nozzle).

Since dynamic numerical simulation of ion motion is rather complicated under such conditions, the goal of this experimental study is to evaluate the efficiency of ion beam transport from a focused source to the first stage of a DPS in a mass spectrometer in the presence of gas- dynamic flow near the nozzle.

Experimental setup and measurement techniques

A schematic of the compact experimental setup for studying ion transport from a focused source through the nozzle to the first stage of the DPS is shown in Fig. 1.

An ion source with positive corona discharge and a focusing system consisting of a corona needle *6* and a set of four thin apertures *1–4*, isolated from each other, are described in detail in our works [10, 11]. A pumping zone simulating the first stage of the DPS of the gas interface is formed behind the fourth aperture with the smallest diameter. This aperture is essentially a nozzle through which gas flows from the atmospheric pressure region into the fore-vacuum region. Collector *9* that is a cylindrical electrode 1.5 mm thick is installed in vacuum chamber *8* to measure the current passing through the nozzle. All electrodes in the setup (except the grounded nozzle) are connected to regulated highly stable high-voltage power supplies *26–30*and electrometers *14–19* measuring currents flowing through the electrodes. Vacuum chamber *8* is pumped out by oil fore-vacuum pump *13* and is equipped with gauge *11* for monitoring the residual gas pressure and gauge *12* for adjusting the pumping rate. The design of the experimental setup provides for the possibility of changing the distance from the crown tip *6* to the counterelectrode *1* (the first diaphragm of the focusing system) and the position of the collector *9* inside the pumping zone.

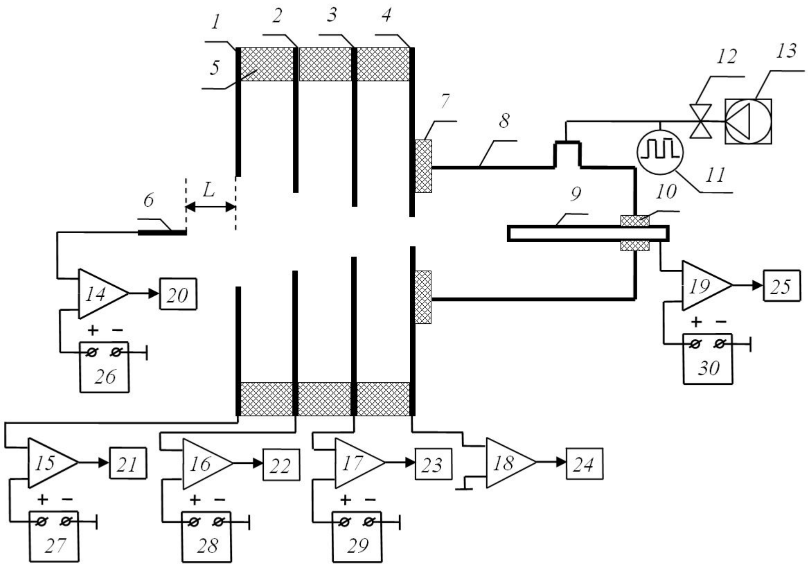

Fig. 1. Schematic of experimental setup:
thin apertures *1–4*, ceramic inserts *5*, corona needle *6*, insulator *7*,
vacuum chamber *8*, collector *9* (copper rod), Wilson sealing ring *10*,
vacuum pressure gauge *11*, valve *12*, fore-vacuum pump *13*, electrometers *14–19*,
digital current meters *20–25*, highly stable high-voltage power supplies *26–30*
The thickness of thin apertures is 0.1 mm, the thickness of ceramic inserts is 1 mm

Results and discussion

The efficiency of ion beam transport to the first stage of the DPS in the considered ion source with focusing is determined primarily by the magnitude of the currents I_c and I_4 measured at the collector and nozzle, respectively. Furthermore, the main trends in redistribution of currents at the electrodes of the system, depending on the potential difference ΔU between the apertures of the focusing system, the distance L from the corona tip to the counter electrode, and the corona discharge current I_p are generally similar to those for the system considered earlier in the absence of gas flow in the vicinity of the nozzle [10]. For this reason, we consider the experimental dependences of the collector and nozzle currents on the pressure in the pumping zone under the following conditions:

corona discharge current I_p = 1 μA,
distance from corona needle to counter electrode L = 7 mm,
potential difference between apertures of focusing system
ΔU varies from -300 to -900 V,
pressure p in vacuum chamber ranges from 750 to 9 Torr,
distance from nozzle to collector is 10 mm,
collector potential U_c = -300 V.

Fig. 2 shows the dependences of the current I_c at the collector, I_4 at the nozzle and the sum of the currents $I_4 + I_c$ on the pressure in the pumping zone at different values of the potential difference ΔU between the electrodes of the focusing system. An increase in the potential difference ΔU from -300 to -900 V is accompanied by an increase in the current I_c measured at the collector by about 1.5 times (making up about 6.7% of the total corona discharge current) and an increase in the current I_4 at the nozzle by about 3.4 times at a pressure of 9 Torr in the vacuum chamber due to an increase in the focusing properties of the system.

Analyzing the distributions of currents arriving at the electrodes, we observe that the currents measured at the first three apertures of the focusing system are practically independent of the pressure in the pumping zone. It can be therefore concluded that the region influenced by the gas flow (discharge into the nozzle) does not exceed the diameter of the hole in the third aperture (1.2 mm) with the nozzle diameter of 0.5 mm. Thus, the size of the region influenced by gas flow can be estimated as two nozzle diameters.

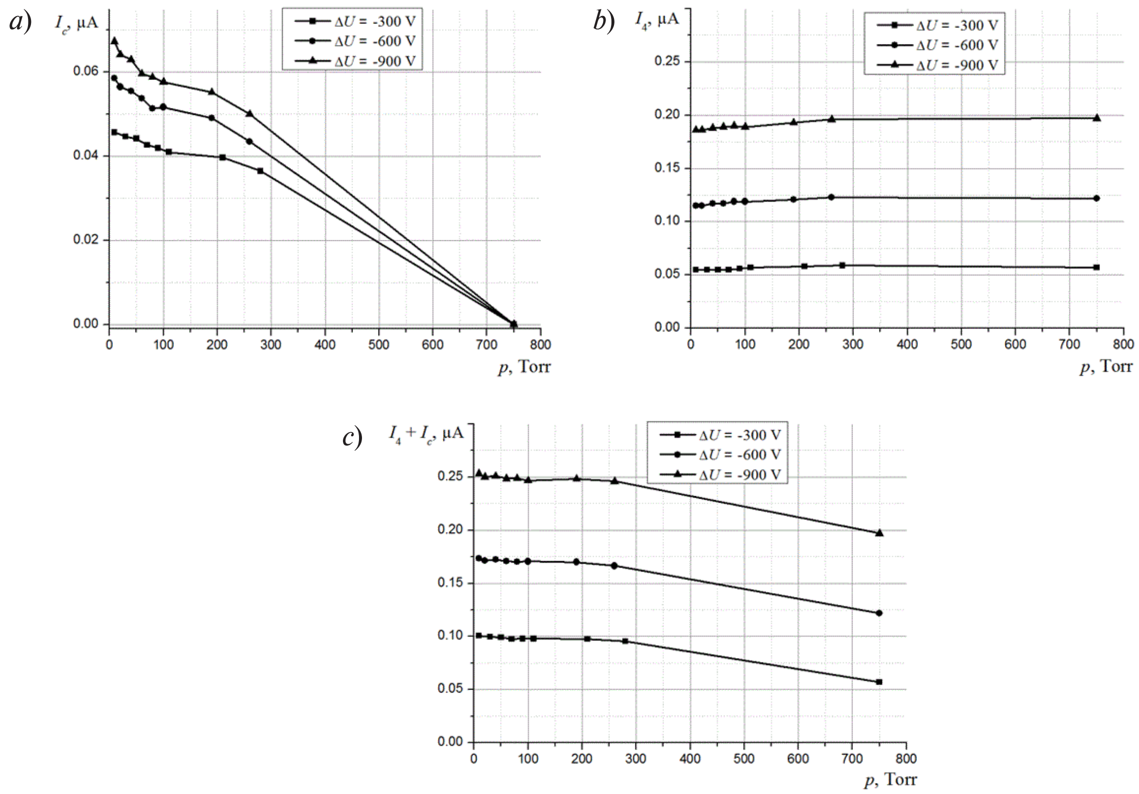

Fig. 2. Current characteristics of ion source with focusing system: dependences of currents I_c fed to collector (*a*), I_4 fed to nozzle (*b*) and sum of currents $I_4 + I_c$ (*c*) on the pressure in the vacuum chamber for different values of potential difference ΔU between apertures

A decrease in pressure behind the nozzle is accompanied by an increase in mass airflow rate. The increase in this flow rate is limited the speed of sound in the critical section of the nozzle, reached at a pressure of about 230 Torr, when the sum of the currents at the nozzle and collector $I_4 + I_c$ becomes nearly constant (see Fig. 2).

The efficiency of a focusing system with thin apertures can be estimated by comparing the efficiency of ion beam transport to the first stage of the DPS in the ion source with and without a focusing system; in the latter case, it is sufficient to replace the wide insulators between the apertures in the circuit under consideration (see Fig. 1) with thin PTFE gaskets 0.1 mm thick. In this case, the initial system of thin apertures is transformed into a grounded quasiplanar counter electrode.

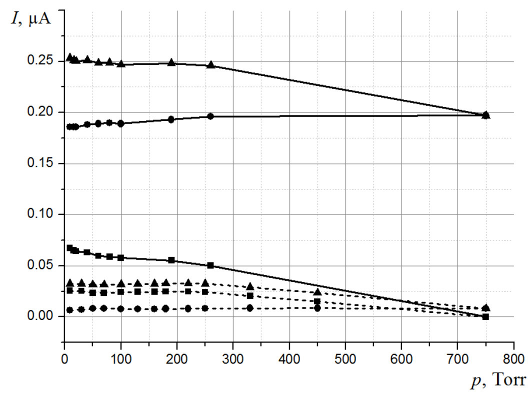

Fig. 3. Comparison of dependences of currents I_c fed to collector (■), I_4 fed to nozzle (●) and sum of currents $I_4 + I_c$ (▲) in ion source with focusing ($\Delta U = -900$ V, solid lines) and without it (dashed lines)

Fig. 3 shows a comparison for the dependences of the currents measured at the collector (I_c), nozzle (I_4), and the sum of the currents $I_4 + I_c$ on the pressure in the vacuum chamber in the ion source with focusing at $U = -900$ V and in the circuit with a quasiplanar counter electrode.

The experimental results obtained demonstrate a threefold increase in the collector current I_c and an increase by almost an order of magnitude (approximately 8 times) in the sum of the currents $I_4 + I_c$ recorded at the nozzle and at the collector using the focusing system in the given experimental conditions.

Table

Comparison of collector currents and sum of currents fed to nozzle and collector in ion source under different experimental conditions

Current in ion source	Current value, nA		I_2/I_1
	I_1	I_2	
I_c	15	67	4.47
$I_4 + I_c$	100	253	2.53

Notations: I_c is the current at the collector; I_4 is the current at the nozzle; I_1 are the currents flowing in the ion source with focusing in stagnant gas; I_2 are the currents in the same region but with gas pumping behind the nozzle. Other experimental conditions: I_p = 1 μA, L = 7 mm, ΔU = -900 V.

We can estimate the influence of gas flow near the nozzle on ion beam transport by comparing the currents fed to the nozzle and collector in the ion source with the focusing system in stagnant gas and under pumping (see Table).

As seen from the data presented, even though the gas flow influences a limited region, it significantly increases the efficiency of ion transport beyond the nozzle, accompanied by an increase in the collector current I_c by about 4.5 times and an increase in the sum of currents $I_4 + I_c$ by 2.5 times. An almost similar increase in currents at the nozzle and collector is experimentally observed in the ion source circuit without focusing and with pumping.

Conclusion

This paper reports on experimental study on the efficiency of ion beam transport to the first stage of the DPS using a focusing system based on thin apertures in a corona discharge source, accounting for both electrostatic ion focusing and gas-dynamic effects in the vicinity of the nozzle. The region where the gas flow (discharge into the nozzle) influences the redistribution of ion current did not exceed two nozzle diameters. Nevertheless, the gas flow significantly increases the efficiency of ion beam transport beyond the nozzle.

The results obtained can serve for further improving the design of ion sources with atmospheric pressure ionization aimed at increasing the sensitivity of the mass spectrometer.

Since electrostatic focusing of the ion beam is accompanied by an increase in the current by almost an order of magnitude, measured at the nozzle, a promising modification of the considered ion-optical circuit for the source is increasing the nozzle diameter, with additional space for differential pumping. This direction is planned as a natural continuation of our research.

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