The Ion Funnel Interface for MALDI Ion Source Operating at Intermediate Pressure

Vadym D. Berkout

MassTech, Inc., Columbia, MD

INTRODUCTION

The advantage of matrix-assisted laser desorption/ionization (MALDI) for the analysis of labile biomolecules performed at intermediate pressures (0.1-1.0 Torr) was demonstrated in recent years. The efficient transmission of ions from the ion source operating at elevated pressures to the mass analyzer operating at high vacuum represents a significant challenge. A considerable work has been done previously to improve ion transmission by using ion guiding devices. The most common ion guide is the radio frequency (RF)-only multipole. A recent development in this field, an ion funnel [1], demonstrated a significant improvement in ion transmission for electrospray ion source. The performance of the ion funnel for MALDI ion source is the subject of this study.

METHOD

Instrumentation

A time-of-flight (TOF) mass spectrometer with orthogonal acceleration, used in our experiments, is described elsewhere [2] . The MALDI ion source was placed in front of the ion funnel at a distance of approximately 10 mm. The ion funnel consisted of a series of ring electrodes with the first electrode of a large internal diameter (21 mm) for effective ion acceptance. The internal diameters of subsequent electrodes were progressively reduced until a 1 mm exit aperture at the last electrode (see Figure 1). The ion funnel was driven by a sine-wave signal generator coupled through a broadband RF power amplifier and phase shifting transformer. By applying RF fields with alternate phases (180 degrees) on adjacent electrodes in conjuction with a DC potential gradient, ions were effectively captured, cooled and transmitted to the next vacuum stage. A quadrupole ion guide was used to transmit ions from the exit of the ion funnel to the TOF mass analyzer.

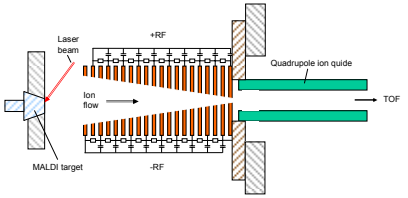

Figure 1. General schematic of the MALDI ion source interface

Peptide ions were produced by a pulsed UV nitrogen laser operating at 5 Hz repetition rate. The samples for mass analysis were prepared on the stainless steel surface by dried-droplet method. Equal amounts of analyte and matrix solution were premixed prior to deposition. Matrix solution (6 mg/mL) was prepared by dissolving 2,5-dihydroxybenzoic acid (DHB) in deionized water/ acetonitrile/ methanol mixture (volume ratios 1:1:1). Analytes were prepared in 0.1% TFA aqueous solutions. The nitrogen gas pressure in the funnel was varied over 0.4-2.2 Torr. The ions were initially accelerated by the electric field between MALDI target and the first ion funnel plate (the potential difference was 120V). The ion transmission was studied as a function of the RF voltages applied to the ion funnel electrodes over 40-200 V_{p-p} range, and frequencies over 0.6-1.8 MHz range. The DC gradient in the ion funnel was kept constant and was 28 V/cm. The quadrupole ion guide, located after the ion funnel, was operated at 500 V_{p-p} , 890 kHz. The pressure in this region was 1-5.5 mTorr, depending on the pressure in the ion funnel region. The acceleration voltage in the orthogonal TOF was 7 kV. The signal from MCP detector was amplified by an Ortec (Oak Ridge, TN) model 9327 1-GHz amplifier and recorded in a 100-ps time digitizer (Ortec model 9353)

RESULTS

Figure 2 shows the dependence of MALDI ion signals on the RF amplitude at 1 MHz frequency. Sample spot contained seven peptides (50 fmole of each): Methionine Enkephaline (m.w. 573.23), Bradykinin fragment 1-7 (m.w. 756.40), Angiotensin II (m.w. 1045.54 Da), Substance P (m.w. 1346.73 Da), Fibrinopeptide A (m.w.1535.69), α-MSH (m.w. 1663.80 Da) , and Adrenocorticotropic hormone (ACTH) fragment 18-39 (m.w. 2464.19) Approximately 300 laser shots were averaged (the spectra were accumulated for 60 s). The nitrogen pressure in the MALDI source was 1.3 Torr. It was found that higher RF voltages were beneficial for transmission of higher masses. At the same time, low m/z cut-off was observed at 160 V_{p-p} applied to the ion funnel. Higher gas pressures had an opposite effect. At optimal conditions (1.8 Torr of nitrogen, 120 V_{p-p} at 1 MHz) it was possible to observe an efficient ion transmission in the m/z range over 500-2500 Da (see Figure 3).

The low mass cut-off at higher RF voltages is most likely caused by a pseudopotential barrier created by oscillating electric potential applied to the last plate of the ion funnel. In adiabatic approximation the pseudopotential, created by this potential, is defined by [3]:

$$V(r) = zeE_0(r)^2 / 4m\Omega^2 \qquad (1)$$

where $E_0(r)$ is an electric field amplitude , Ω – angular frequency. The estimates show that this potential creates a barrier of a few Volts for typical experimental conditions. Its value increases with RF amplitude and is higher for lower masses. At higher gas pressures in the funnel, the gas flow velocity is increased, dragging the lower masses across the barrier and thus increasing transmission of lower mass ions.

The mass spectra obtained with the ion funnel interface were compared to the spectra obtained with quadrupole ion guide mounted in front of MALDI target [4]. The pressure of nitrogen was about 0.12 Torr in this case. Ion signals were higher (3-5 times) for the ion funnel.

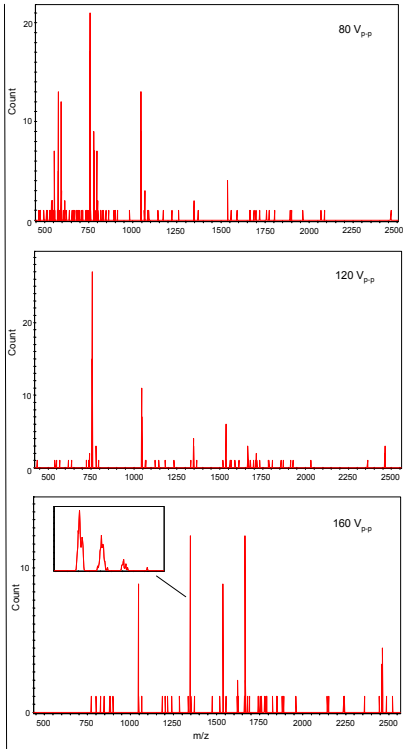

Figure 2. MALDI spectra of peptide mixture at different RF voltages (1MHz, 1.3 Torr N_2).

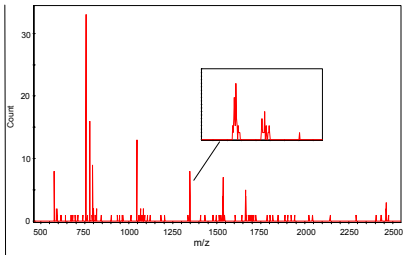

Figure 3. MALDI spectrum of peptide mixture (120 V_{p-p} at 1 MHz , 1.8 Torr N2).

CONCLUSIONS

The performance of the ion funnel coupled to MALDI ion source as a function of different parameters (RF voltage, gas pressure) was studied.

The ion funnel demonstrated much higher ion transmission compared to quadrupole ion guide

ACKNOWLEDGEMENTS

This work was supported by SBIR/NIH program (*5R44RR017467-03*). Also, author thanks Drs. Vladimir Doroshenko and Mikhail Gorshkov for helpful discussions.

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