

The apparatus and method of the invention can be used alone or in conjunction with other established devices and methods that lessen detrimental effects associated with excessive space charge. Central to this technique is the exploitation of kinetic energy distributions of low  $m/z$  ion species.

#### BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a cross-sectional illustration of an ion funnel that includes a conductance limit electrode as a filter plate and a jet disrupter electrode.

FIGS. 2a-2b illustrate configurations for low- $m/z$  filtering in conjunction with use of an ion funnel, according to two embodiments of the invention.

FIGS. 3a-3c present mass spectra of a calibration solution taken in conjunction with an ion funnel filter plate at 8V, 13.6 V, and 17.6 V, respectively.

FIGS. 4a-4b present mass spectra of a solvent solution taken without and with low-mass filtering, respectively, filtering being done at an applied voltage of from about 12 V to about 18 V providing low-mass ( $m/z$ ) cut-off at below about 200.

FIG. 4c is a plot relating ( $m/z$ ) cut-off (mass filtering) of the filter plate as a function of voltage applied to the filter plate.

FIG. 5a is a plot of the calculated DC potential for a filtering plate voltage of 15 V as a function of distance along the ion funnel z axis with radial off-axis displacements "r" in the region near the filter plate.

FIG. 5b is a plot of the axial electric field strength (E) for a filtering plate voltage of 15 V as a function of distance along the ion funnel z axis in the region near the filter plate.

FIG. 5c is a plot of the electric field maximum (E) calculated as a function of voltage ( $V_{fp}$ ) applied to the filter plate.

FIG. 6a is a mass spectrum of a polyethylene glycol solution taken at an RF voltage of 80 V<sub>p-p</sub> (peak-to-peak) without use of the mass filter plate.

FIGS. 6b-6f are mass spectra of a polyethylene glycol solution taken at RF voltages (peak-to-peak) of 100 V<sub>p-p</sub> (FIG. 6b), 90 V<sub>p-p</sub> (FIG. 6c), 80 V<sub>p-p</sub> (FIG. 6d), 70 V<sub>p-p</sub> (FIG. 6e), and 60 V<sub>p-p</sub> (FIG. 6f) using a filter plate at a mass filter voltage of 24.0 V and a mass ( $m/z$ ) filter cut-off of  $m/z=1100$ .

FIGS. 7a-7b present ion-current chromatograms from LC-MS analyses of a Bovine Serum Albumin (BSA) tryptic digest solution without and with use of a mass filter plate.

#### DETAILED DESCRIPTION

While the present disclosure is exemplified by specific embodiments, it should be understood that the invention is not limited thereto, and variations in form and detail may be made without departing from the spirit and scope of the invention. All such modifications as would be envisioned by those of skill in the art are hereby incorporated.

The present invention relates generally to method and apparatus for selective ion filtering. More particularly, the invention relates to a method and apparatus for filtering of low- $m/z$  ions in conjunction with use of an electrodynamic ion funnel. The mass filtering approach described herein provides a simple means for reducing space-charge. The approach selectively eliminates undesired ions, lowering the ion population and unwanted space-charge effects associated with the same thereby enhancing instrument performance.

In one embodiment, the invention employs an ionization source, an ion funnel, and the low-mass filter in combination providing a simple means to reduce the amount of space charge in the receiving instrument by blocking (filtering) ions in a defined, lower-mass region. The combination is effective

for at least the following reasons. First, most of the background ion current is typically made up of low-mass species that are often solvent or matrix derived. Secondly, many MS applications, e.g., proteomics, do not utilize low  $m/z$  species. In peptide and protein, analyses (e.g., LC-MS), the mass range of interest is typically higher than an  $m/z$  of about 200. Thus, the low  $m/z$  filter can be employed without adversely affecting the analysis. Additionally, the ability to easily and dynamically set the maximum  $m/z$  cut-off of the filter allows for the tailoring of the device to better match the  $m/z$  range requirements of various samples. Further, the use of variable low-mass filtering in an electrodynamic ion funnel can be used alone or in conjunction with other space charge limiting techniques (such as automated gain control) to increase mass spectrometer performance and provide improved data quality.

FIG. 1 illustrates a longitudinal, cross-sectional view of an ion funnel 10 configured with a conductance limiting or terminating electrode 40, that, in conjunction with the preferred embodiment of the method of the invention, can act as a mass ( $m/z$ ) filter (hereafter called filter plate 40), as described and demonstrated hereafter. Ion funnel 10 is a special ion guide tapered to improve transmission efficiency of ions in the interface region (not shown) between an ionization source 25, e.g., an Electrospray Ionization Source (ESI), and a mass-selective instrument or analyzer 30, e.g., mass spectrometer 30. In the figure, ion funnel 10 comprises a stack of (e.g., 100) ring electrodes or plates 35, but is not limited thereto. Electrode plates 35 begin to exhibit sequentially decreasing aperture diameters at about the midpoint of the stack, culminating in a conductance limit (smallest aperture) electrode 40 positioned in rear section 45 of funnel 10. Funnel 10 operates in conjunction with a superimposed radio frequency (RF) voltage and a DC gradient that spans the length of funnel 10. Electronics that co-apply RF and DC potentials and/or gradients, including, but not limited to, e.g., a uniform ladder of DC voltages in various modes to a series of electrodes is detailed, e.g., in Smith et al. (U.S. Pat. No. 6,107,628) which is incorporated herein by reference. All electrode configurations and processes as will be selected by those skilled in the art in view of the disclosure are incorporated herein by reference. No limitations are intended.

In the figure, ion funnel 10 includes a jet disrupter 50, which is, e.g., a 6.5 mm diameter metal disk located about one inch from the funnel 10 inlet 55 electrically isolated from voltages of the ion funnel 10 and controlled by an independent DC power supply 60. Jet disrupter 50 disperses the gas jet exiting the heated capillary of ion funnel 10, reducing the gas load to a subsequent stage and prohibits neutrals from entering the mass spectrometer.

Mass filter 40 is easily implemented, independent of the type of instrument, and is contained solely within ionization source 25 thereby eliminating the need to change any elements or potentials in the mass spectrometer. The MS analyzer employed in conjunction with the invention may be of any type, including but not limited to sector, quadrupole, time-of-flight (ToF), quadrupole trap, orbitrap, Fourier-transform ion cyclotron resonance (FTICR), or combinations thereof. In addition, the MS analyzer can be coupled to other instruments, devices, tools, software, reagents, and/or consumables as will be understood and/or contemplated by those of skill in the art, without limitation.

When a DC voltage (potential) is applied to filter plate 40 or the conductance limiting electrode 40 of ion funnel 10, an energy barrier (electric field) is generated, filtering (e.g., blocking) low mass ( $m/z$ ) ions from exiting the ionization source 25 through exit aperture 65. The barrier potential