

to drastically improve sensitivity of IMS/TOF-MS instruments. While the ion funnel trap is described herein in conjunction with coupling to an orthogonal acceleration time-of-flight (TOF) mass spectrometer (oa-TOF-MS) for analysis of peptides, the invention is not limited thereto. Here the oa-TOF-MS is equipped with analog-to-digital converter detection. The ion trap operates at a pressure of ~ 1 Torr and is characterized by a fast ion ejection time of $< 100 \mu\text{s}$. Further increases in trap pressure are feasible, provided adequate ion ejection is implemented. Results show improvements in ion packet charge density are accompanied by 10-30-fold gains in signal-to-noise ratio (SNR) with respect to signals obtained using the same instrument operating in the continuous mode. The trap is optimized for operation at higher pressures. 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 ion trap will now be described with reference to FIG. 1a and FIG. 1b.

[0019] FIG. 1a is a schematic view of an ion funnel trap (IFT) 100, according to a preferred embodiment of the invention. In the figure, IFT 100 includes an inlet portion 10 that has a diverging geometry that maximizes expansion of an ion plume received from a preceding stage; a trapping portion 20 configured to trap and accumulate ions, and an outlet portion 30 that has a converging geometry that focuses ions released from the trapping portion. In the figure, inlet portion 10 includes a number of concentric ring electrodes 12, which number is not limited. Electrodes 12 in the inlet portion expand in diameter [inner diameter, (i.d.)] from, e.g., about 3 mm in a first electrode to 19.1 mm in a last electrode, which dimensions are not limited. The first electrode in inlet portion 10 couples the inlet portion to a preceding stage.

[0020] Trapping portion 20 includes a number of concentric ring electrodes 14 of equal diameter, which number is not limited. Electrodes 14 in the trapping portion each with an inner diameter, e.g., of 19.1 mm, which dimensions are not limited. Trapping portion 20 accumulates and traps ions between subsequent ion accumulation and ion release cycles, with the accumulation and release cycles performed in conjunction with ion gating, described further herein. The trapping portion couples with, and releases ions to, outlet portion 30.

[0021] Outlet portion 30 includes a number of concentric ring electrodes 16, which number is not limited. Electrodes 16 in the outlet portion decrease progressively in diameter, e.g., from 19.1 mm down to, e.g., 2.4 mm at the conductance limit (or final) electrode of the IFT, which dimensions are not limited. The conductance limit electrode interfaces the IFT to a subsequent ion analysis stage, e.g., an ion mobility drift cell, an rf-multipole interface of a TOF-MS instrument, or other stages, e.g., IMS/IMS-TOF instruments. Refocusing of disperse ion packets released from the trapping portion of the IFT increases sensitivity of ion analysis in the subsequent ion stages.

[0022] In the figure, trapping portion 20 is separated from inlet portion 10 and outlet portion 30 by high-transmission electrostatic grids (ion gates) 18 (e.g., 95% transmission, nickel mesh, 20 lines/inch), here shown with an entrance grid 18(a), a trapping grid 18(b), and an exit grid 18(c), but is not limited thereto. Entrance grid 18(a) is positioned at the entrance to trapping portion 20. Trapping grid 18(b) and exit

grid 18(c) are positioned on the exit side of the trapping portion. The dual grid configuration at the exit results in faster ion ejection from the IFT, which improves efficiency and allows concentrations of ions directly preceding the trapping grid to be increased.

[0023] In the instant embodiment, three (3) dc-gradient controls 22 couple through selected $100 \text{ k}\Omega$ resistors 24 to preselected ring electrodes 14 within trapping portion 20 and ring electrodes 16 positioned adjacent to the trapping portion within outlet portion 30. Each gradient control 22 provides control of dc gradients in the ion trap. For example, two dc-gradient controls 22 positioned near entrance grid 18(a) and trapping grid 18(b) of trapping portion 20, respectively, permit adjustment of the dc-gradient within the trapping portion. A third dc-gradient control 22, i.e., an ejection gradient control, generates an electric field that guides ions released from the trapping portion into outlet portion 30. A fourth dc-gradient control (not shown) may be coupled directly to a conductance limit, or last, electrode at the exit of outlet portion 30 to assist flow of ions to a subsequent stage. Release and ejection of ions from the IFT are assisted not only by pulsed potentials applied to the entrance grid and the trapping grid through trap gradient controls 22, but also by dc-potentials applied to resistors that couple to the IFT electrodes, e.g., as a chain of resistors, described further herein. Speed of ion ejection from the IFT drastically improves at pressures greater than or equal to about 1 Torr. Ability to control speed of ion ejection is particularly attractive for interfacing to, e.g., IMS or IMS-TOF-MS instruments. In a preferred configuration, illustrated in FIG. 1b, IFT 100 couples with an electrodynamic ion funnel 105 which is used as a preceding ion stage, described further in reference to FIG. 2.

[0024] FIG. 2 is a lengthwise cross-sectional view showing the bottom half of ion funnel trap (IFT) 100. In the figure, the IFT is coupled with an electrodynamic ion funnel 105 which is used as a preceding ion stage. In the instant configuration, electrodes of the ion funnel and of the IFT are assembled onto four ceramic rods (not shown) through entry holes 120 (two are shown) that ensure proper axial alignment of both the ion funnel and IFT. In an exemplary embodiment, each electrode of the IFT is 0.5 mm thick and is separated from subsequent or preceding electrodes by a 0.5 mm spacer 125 composed of polytetrafluoroethylene, also known as TEFLON®. Spacers positioned between each funnel electrode and trap electrode ensure that the funnel pressure matches ambient gas in the ion funnel trap. Ions received from the ion funnel are introduced to inlet portion 10 and delivered to trapping portion 20 and accumulated. Entrance grid 18(a) and trapping grid 18(b) provide trapping of ions within the trapping portion. Ions accumulated in the trapping portion are subsequently released to outlet portion 30 through exit grid (not shown), and focused and delivered to a subsequent ion stage as described previously herein.

[0025] FIGS. 3a-3f illustrate various exemplary inner geometries of electrodes of the ion trap, which geometries are not intended to be limiting. All geometries as will be considered or implemented by those of skill in the art in view of the disclosure are within the scope of the invention. In the figure, each of the inner geometries is symmetric in either the X plane, the Y plane, and/or the X/Y plane with respect to the Z-axis. Here, the Z-axis refers to the axial dimension of the ion trap. As will be understood by those of skill in the art, electrodes geometry of electrodes can be rotated with respect to the Z-axis dimension. The term "symmetric" as used herein