ION FUNNEL ION TRAP AND PROCESS

[0001] This invention was made with Government support under Contract DE-AC05-76RLO1830 awarded by the U.S. Department of Energy. The Government has certain rights in the invention.

FIELD OF THE INVENTION

[0002] The present invention relates generally to instrumentation and methods for guiding and focusing ions in the gas phase. More particularly, the invention relates to an ion funnel ion trap and method for transmission of ions between coupled stages, e.g., for separation, for characterization, and/or for analysis of preselected ions at different gas pressures.

SUMMARY OF THE INVENTION

[0003] The invention is a system for ion analysis that includes an ion funnel ion trap (IFT) that comprises: an inlet portion defined by electrodes that diverges ions in an ion beam introduced thereto to expand same; a trapping portion defined by electrodes that operatively couple to the inlet portion and traps and accumulates a preselected quantity of ions received from the inlet portion. The trapping portion includes an electrostatic grid that controls entry of ions from the inlet portion and one or more electrostatic grids that control outflow of a preselected quantity of ions accumulated in, or otherwise released from, the trapping portion; and an outlet portion that is defined by electrodes that are operatively coupled to the trapping portion and serve to converge preselected ions released from the trapping portion. Electrodes of the ion trap have an inner geometry that is symmetric in the X plane, the Y plane, and/or the X/Y plane with respect to the Z-axis (axial axis) of the ion trap. The ion trap has an inner electrode geometry cross section selected in the range from about 0.02 mm to about 20 mm. Electrodes of the ion trap are equipped to include an rf-potential that is phase shifted 180 degrees from a subsequent electrode in the ion trap. The inlet portion is defined by a series of axially aligned concentric ring electrodes that collectively define an ion flow path. Each electrode in this series has an inner geometry perimeter that is equal to, or greater than, an electrode preceding it in the series. Length of the inlet portion is not limited and is a function of the diameter of the trapping portion. In an exemplary embodiment, length of the inlet portion is ~5 mm long. The inlet portion includes an electrode that couples the inlet portion to a conductance limit of a preceding ion stage. In a preferred configuration, the inlet portion couples with, or is integrated with, an electrodynamic ion funnel as the preceding ion stage. The trapping portion of the IFT includes a series of axially aligned concentric ring electrodes. Each electrode in the trapping portion has an inner geometry perimeter that is equal to, smaller than, or greater than, an electrode preceding it in the series of electrodes that make up the trapping portion. The trapping portion includes a series of axially aligned concentric ring electrodes. Each electrode in the trapping portion has an inner geometry perimeter that is equal to, smaller than, or greater than, an electrode preceding it in the series. The inner geometry perimeter is preferably selected in the range from about 10 mm to about 30 mm, but is not limited. The trapping portion provides for accumulation of preselected quantities of ions therein. In a preferred embodiment, the trapping portion includes three electrostatic grids, an entrance grid; a trapping grid; and exit grid. The entrance grid controls entry of ions received from the inlet portion into the trapping portion. Trapping grid provides for accumulation of ions for preselected time periods in the trapping portion, e.g., in close proximity to the exit of the trapping portion. The trapping grid further minimizes effects of electric field penetration into the trapping portion. The exit grid prevents ions received in a continuous ion beam into the trapping portion from escaping the trapping portion during the accumulation period, and releases selected ions during an extraction period from the trapping portion at a preselected rate into the outlet portion. Grids are preferably composed, e.g., of a metal mesh (e.g., nickel mesh) with preselected densities, e.g., a density of about 20 lines/inch that define, e.g., adjacent transmission squares or other shapes in the mesh, which densities and shapes are not limited. The trapping grid and the exit grid are positioned a preselected separation distance apart from each other on the exit side of the trapping portion. The separation distance is on the order of the spacing between adjacent squares in the grid mesh. The trapping portion is configured to deliver a trap gradient that is provided by one or more trap gradient controls. The trap gradient controls couple to various dc-electrodes in the IFT and provide preselected dc-potentials to each of these dc-electrodes which deliver the trap gradient in the trapping portion of the IFT. In an exemplary configuration, a trap gradient control is electrically coupled to a dc-electrode positioned adjacent to, and/or following, an electrostatic entrance grid; another dc-electrode is positioned adjacent to, and/or prior to, an electrostatic trapping grid, and/or an electrostatic exit grid. The trap gradient controls provide preselected dc-potentials to the dc-electrodes. The trapping portion can also be equipped with two electrostatic grids, e.g., an entrance grid and an exit grid, or an entrance grid and a trapping grid. The electrostatic grids can be dc-only grids, but are not limited. An rf-potential can also be simultaneously applied to each of the electrodes of the ion trap that is phase shifted 180 degrees from any other subsequent electrode in the ion trap. The outlet portion of the IFT includes a series of axially aligned concentric ring electrodes that define an ion flow path. Electrodes in this series have an inner geometry perimeter that is equal to, or smaller than, an electrode preceding it in the series. The electrodes of the outlet portion converge and focus ions released from the trapping portion into the outlet portion and introduces ions into a subsequent ion stage. The outlet portion can include an ejection gradient control that couples to a dc-electrode positioned adjacent to an electrostatic grid in the trapping portion, e.g., the exit grid. The ejection gradient control provides a preselected potential to the dc-electrode and moves the preselected ions from the trapping portion into the outlet portion. The outlet portion includes a conductance limit that couples the ion trap to a subsequent ion stage and introduces ions released from the trapping portion at a preselected pressure to the ion stage. Ion stages include, but are limited to, e.g., TOF-MS, IMS, or other ion and analysis instruments. The conductance limit has an inner geometry perimeter that is equal to, or smaller than, an inner geometry perimeter of a subsequent ion stage. Electrodes of the outlet portion define a preferred converging angle of about 30 degrees that minimizes ion losses at the conductance limit of the outlet portion. The outlet portion has a length that depends on the inner geometry perimeters of the trapping portion.

[0004] The ion trap provides accumulation of ions that enhances sensitivity of selected ions. These ions are delivered