gas pressure is precluded in macroscopic gaps by electrical breakdown in the gas, but is permitted in the instant invention by microscopic gaps that have a higher breakdown threshold.

In some embodiments, the device operates at ambient atmospheric pressure. In other embodiments, the pressure ranges from 50 Torr to about 1 atm. In yet other embodiments, the pressure ranges from about 1 atm to 5 atm. In various embodiments, the thickness of electrodes and width of inter-electrode gaps ranges from 10 μm to 200 μm and particularly from 10 μm to 75 μm. In some embodiments, the electrode thickness ranges from ⅓ to 3 times the width of gaps between them and particularly equals that width. In various embodiments, the RF field frequency ranges from 10 MHz to 150 MHz and particularly from 25 MHz to 60 MHz.

In various embodiments, the electrodes are plates with internal apertures of any geometry arranged in a stack, where neighboring plates carry opposite phases of an alternating voltage. Ions are conveyed through the apertures sequentially across the stack while the Dehmelt force repels ions inside from the aperture circumference. In some embodiments, ions are propelled along the stack by a time-independent longitudinal electric field derived from a ladder of fixed voltages applied to the plates in addition to the RF voltage. In other embodiments, ions are propelled along the stack by a gas flow resulting from vacuum suction into a following instrument stage at a lower pressure including, but not limited to, a mass spectrometer, an ion mobility spectrometer, a photoelectron spectrometer, a photodissociation spectrometer, and combinations of these stages. In some embodiments, the apertures have essentially the same geometry and cross-sectional area, defining an ion-guiding tunnel. In other embodiments, the apertures have homologous shapes and cross-sectional areas that decrease along the stack, defining a funnel that focuses ion beams entering the stack through an entrance aperture into tighter beams exiting through a smaller terminal aperture. In other embodiments, the apertures have homologous shapes and cross-sectional areas that increase in preselected segments and decrease in other segments along the stack, defining hourglass ion funnels, wherein regions having wider apertures for ion storage are separated by regions of narrower apertures for ion focusing.

In some embodiments, the electrodes are patterned on, or attached to, a preselected surface, forming a periodic grating such that the Dehmelt force repels ions from the surface. In particular, the electrodes may display a surface of metal or other electrically conductive material deposed on an insulating substrate body. In some embodiments, ions are moved along the preselected surface by a longitudinal electric field derived from a ladder of fixed voltages applied to the electrodes in superposition with RF voltages.

In one embodiment, at least two of the preselected surfaces are disposed at an angle forming a wedge funnel with an open slit at the apex. Ion beams entering the open base of the wedge are compressed in one dimension, forming a narrower belt-shaped beam exiting through said slit. Ions are propelled through the wedge by a longitudinal electric field derived from a ladder of fixed voltages applied to the elements on the preselected surfaces, a gas flow resulting from vacuum suction into a following instrument stage, or a combination thereof.

In some embodiments, the device receives ions from a linear or elongated rectangular array of elementary sources such as an electrospray (ESI) emitter array or a plate for matrix-assisted laser desorption ionization (MALDI). In other embodiments, the device is disposed at or after the IMS analyzer terminus to compress ion packets exiting therefrom into the rectangular parallelepiped geometry for injection into

another instrument stage. In still other embodiments, the device is disposed at or after the terminus of a differential mobility analyzer (DMA) or FAIMS analyzer of planar or transverse-cylindrical gap geometry to compress the belt-shaped ion beams exiting from these stages for injection into another stage. In different embodiments, the stage following the device is an MS stage, an IMS stage, a photoelectron spectrometer, a photodissociation spectrometer, or a combination thereof. In some embodiments, the belt-shaped ion beam exiting a wedge funnel is refocused into a circular or other cross-sectional shape using a following ion funnel at a gas pressure lower than that inside the wedge. In other embodiments, the belt-shaped ion beam is introduced into a subsequent IMS stage in a continuous or pulsed mode, and separated or filtered therein while retaining a rectangular cross section. Here, the IMS stage may be DTIMS, traveling-wave IMS, DMA, or FAIMS, or a combination thereof. In other embodiments, the belt-shaped ion beam is extracted from an IMS stage with compression that retains its rectangular r cross section for introduction into another analyzer including IMS stages, photoelectron spectrometers, photodissociation spectrometers, and combinations thereof. In other embodiments, the belt-shaped beam is injected into a subsequent MS stage, in a continuous or pulsed mode, and analyzed therein while retaining a rectangular cross section. In particular, the MS stage may be a ToF mass spectrometer, with the lateral span of the belt-shaped beam orthogonal to both the directions of ion velocity in MS analysis and ion injection into the ToF instrument. In one embodiment, the belt-shaped beam is injected into an IMS stage, separated therein, and extracted and injected into an MS stage while retaining the rectangular cross section such that the whole IMS/MS separation is performed on a planar ion beam.

BRIEF DESCRIPTION OF THE DRAWINGS

FIGS. **1**a-**1**e (prior art) show conventional designs for desolvation of ions produced by ESI.

FIGS. **2**a-**2**d (prior art) show different conical ion funnel designs.

FIGS. **3**a-**3**b show FAIMS and MS spectra for a tryptic digest of bovine serum albumin obtained in helium using an ion mobility microchip.

FIGS. **4**a-**4**c show various wedge ion funnel configurations, according to different embodiments of the invention.

FIGS. **5**a-**5**c show various composite ion funnel schemes, according to different embodiments of the invention.

FIG. **6** shows exemplary ion beam shapes produced in accordance with different embodiments of the invention.

FIG. **7** shows beneficial use of a belt-shaped ion beam in the following time-of-flight MS analyzer, according to an embodiment of the invention.

FIG. **8** shows beneficial use of a belt-shaped ion beam in the following drift-tube IMS analyzer, according to another embodiment of the invention.

FIGS. **9**a-**9**c show a "wedge" ion funnel interfaced after different ion sources, according to various embodiments of the invention.

FIG. **10** shows a system comprising "wedge" ion funnels that enables complete "cradle-to-grave" in-plane ion analysis, according to an embodiment of the invention.

DETAILED DESCRIPTION

The invention provides effective RF ion focusing across the range of ion mass-to-charge ratios most relevant to proteomics and metabolomics (~300-3,000) at P>0.1 atm. In