

may be orthogonal or inline with ion beam 20. The second "hooked" DMS element 12, receiving ions from DMS analyzer 10, is in front of subsequent stage 32, e.g., an MS or IMS. Analyzer 10 filters ions using a uniform electric field 26. Electrode 14 carries  $U_D(t)$  and electrode 16 carries the CV that jointly establish inhomogeneous electric field 28 over gap 18 which focuses ion beam 20 introduced thereto toward the gap median. Thus, beam 20 is compressed, becoming thinner compared to diffuse beam 20 received from preceding stage 22 (for first element 12) or DMS analyzer 10 (for second element 12). Ion beam 20 entering apparatus 200 is more effectively injected into DMS analyzer 10 and the beam exiting apparatus 200 is more effectively transmitted via aperture 30 to subsequent stage 32. In the instant embodiment, each stage 12 provides an angular turn of about  $90^\circ$  as measured from the drift vector in DMS analyzer 10 to which each element 12 is coupled or integrated, but is not limited.

[0039] In other embodiments, curved electrodes 14 and 16 receive ions from two planar DMS analyzers 10. In yet other embodiments, curved electrodes 14 and 16 deliver ions to two planar DMS analyzers 10. All configurations as will be contemplated by those of skill in the art in view of the disclosure are within the scope of the disclosure.

[0040] FIG. 3 illustrates a cross-section of a "hooked" DMS apparatus 300, according to yet another embodiment of the invention. In the instant embodiment, two planar DMS analyzers 10 are each coupled to, or integrated with, two DMS elements 12 each comprising two curved electrodes 14 and 16 with a gap 18 therebetween that receives ion beam 20 from either ion source or preceding stage 22 via aperture 24 or from a planar DMS analyzer 10. The first "hooked" DMS element 12 with angular span of  $180^\circ$  is coupled to ion source 22 and integrated with the ends of both planar DMS analyzers 10. The second "hooked" DMS element 12 with the same angular span is integrated with the other ends of both planar DMS analyzers 10 and positioned in front of subsequent stage 32, e.g., an IMS or MS. Curved electrodes 14 and 16 of first element 12 split ion beam 20 introduced from ion source or preceding stage 22 between two analyzers 10, each filtering ions received using a uniform electric field 26. Electrodes 14 in each element 12 carry  $U_D(t)$  and electrodes 16 carry the CV that jointly establish a spatially inhomogeneous electric field 28 over gap 18 that focuses ion beam 20 introduced thereto toward the gap median. Thus, beam 20 is compressed, becoming thinner compared to diffuse beam 20 received from preceding stage 22 for first element 12 or either DMS analyzer 10 for second element 12. Ion beam 20 entering apparatus 300 is more effectively injected into DMS analyzers 10 and the beam exiting apparatus 300 is more effectively transmitted via aperture 30 to subsequent stage 32. In the instant embodiment, each stage 12 provides an angular turn of about  $90^\circ$  as measured from the drift vector in DMS analyzer 10 to which each element 12 is coupled, but is not limited. Other instrument configurations are envisioned, e.g., with ions injected into and/or ejected from the elements 12 at other than their midpoints. No limitations are thus intended.

[0041] FIG. 4 presents a perspective view of an outer casing or enclosure 400 for enclosing an embodiment of a "hooked" DMS apparatus (FIG. 1) of the invention. Casing 400 includes a top part 402, a lid 404, a side panel 406, a bottom part 408, and an adaptor 410 machined out of a vacuum-compatible plastic, e.g., commercial Polyetheretherketone (PEEK®) (McMaster-Carr, Los Angeles, Calif., USA). In the exemplary embodiment, the planar DMS analyzer is formed by planar parts of two polished stainless steel electrodes

precisely positioned inside enclosure 400 by ceramic spacers (not shown). Gap dimensions are 2 mm (width), 30 mm (length), and 20 mm (span). Ions are focused in a 2-mm annular gap between the cylindrical parts of two electrodes, with an inner radius of 8 mm and an outer radius of 10 mm.

[0042] FIG. 5 presents an exploded view of outer casing 400 of FIG. 4 showing parts of the exemplary embodiment of a "hooked" DMS apparatus 100 enclosed therein. Electrodes 14 and 16, described in reference to FIG. 1, comprise planar segments forming an analyzer 10 and cylindrical segments forming element 12 integrated into contiguous structures, but are not limited thereto. For example, planar and curved segments may be fabricated separately and joined by bolting, fastening, welding, soldering, gluing, and other methods without limitation. Electrodes 14 and 16 are positioned in parallel with a defined gap therebetween (FIG. 6) enclosed within casing 400. A gas inlet 502 in top part 402 introduces carrier gas into the gap found beneath curtain plate 504 through aperture 508 in curtain plate 504 and aperture 506 in electrode 16. Plate 504 is seated in, and secured to, top part 402. Adaptor 410 attaches apparatus 100 to inlet 30 of subsequent stage 32.

[0043] FIG. 6 presents a cross-sectional view of the exemplary embodiment of a "hooked" DMS apparatus 100 assembled within the casing 400 of FIG. 4 described previously, including dimensions. Gas inlet 502 allows introduction of a suitable gas as will be known by those of skill in the art, including, e.g.,  $N_2$ , He,  $O_2$ ,  $CO_2$ ,  $SF_6$  and the like or mixtures thereof, providing: 1) a curtain gas to curtain plate 504 for desolvation of ions introduced thereto from an ion source (FIG. 1), e.g., an ESI emitter, and 2) a carrier gas to gap 18 between electrodes 14 and 16.

[0044] FIG. 7 illustrates an exemplary integrated DMS/MS instrument 500 involving a "hooked" DMS apparatus 100 of the invention and TOF MS stage 32. The person of skill in the art will understand that the configuration is illustrative, not exclusive. Thus, no limitations are intended. In the figure, apparatus 100 is coupled to ion source 22, here an ESI emitter. Ions enter gap 18 through curtain plate 504 or other suitable ESI/DMS interface. In the instant configuration, curtain plate aperture 508 and ion sampling aperture 506 have diameters of 2.5 mm and 1.5 mm, respectively. Carrier gas 510 enters through a gas inlet 502 or side opening in the top part of the casing (FIG. 5) and splits into two streams. A major stream flows out of curtain plate aperture 508 and desolvates ions incoming from ion source 22, while a minor stream carries ions into sampling aperture 506 and through gap 18. The exit from gap 18 opposes aperture 30, with a  $\sim 0.5$  mm break left for electrical insulation and escape of excess carrier gas 510. Gas is supplied by a gas sourcing unit 512 (Thermo-Fischer Scientific, Waltham, Mass., USA) that formulates gas mixtures of up to three components each pre-dried by hygroscopic filters and controls the flow rate in the 0.5-5 L/min range. For example, He/ $N_2$  mixtures can be supplied with compositions of 10% to 80% He (v/v) at total flow rates of  $\sim 1.5$ -4 L/min, but is not limited thereto. ESI emitter 22, mounted on an X-Y translation stage for fine position adjustment, is installed a few mm away from curtain plate aperture 508. Samples are infused to emitter 22 at a typical flow rate of 0.4  $\mu$ L/min through a metal union, e.g., using a pump-driven microsyringe (KD Scientific, Holliston, Mass., USA). The CV is generated by a programmable dc power supply (Thermo-Fischer) 514, with waveform applied to electrode 14 and CV applied to electrode 16. The DV is adjustable from