

ION TRANSFER TUBE WITH SPATIALLY ALTERNATING DC FIELDS

FIELD OF THE INVENTION

[0001] This invention relates to an ion transfer arrangement, for transporting ions within a mass spectrometer, and more particularly to an ion transfer arrangement for transporting ions from an atmospheric pressure ionisation source to the high vacuum of a mass spectrometer vacuum chamber.

BACKGROUND OF THE INVENTION

[0002] Ion transfer tubes, also known as capillaries, are well known in the mass spectrometry art for the transport of ions between an ionization chamber maintained at or near atmospheric pressure and a second chamber maintained at reduced pressure. Generally described, an ion transfer channel typically takes the form of an elongated narrow tube (capillary) having an inlet end open to the ionization chamber and an outlet end open to the second chamber. Ions, together with charged and uncharged particles (e.g., partially desolvated droplets from an electrospray or APCI probe, or Ions and neutrals and Substrate/Matrix from a Laser Desorption or MALDI source) and background gas, enter the inlet end of the ion transfer capillary and traverse its length under the influence of the pressure gradient. The ion/gas flow then exits the ion transfer tube as a free jet expansion. The ions may subsequently pass through the aperture of a skimmer cone through regions of successively lower pressures and are thereafter delivered to a mass analyzer for acquisition of a mass spectrum.

[0003] There is a significant loss in existing ion transfer arrangements, so that the majority of those ions generated by the ion source do not succeed in reaching and passing through the ion transfer arrangement into the subsequent stages of mass spectrometry.

[0004] A number of approaches have been taken to address this problem. For example, the ion transfer tube may be heated to evaporate residual solvent (thereby improving ion production) and to dissociate solvent-analyte adducts. A counterflow of heated gas has been proposed to increase desolvation prior to entry of the spray into the transfer channel. Various techniques for alignment and positioning of the sample spray, the capillary tube and the skimmer have been implemented to seek to maximize the number of ions from the source that are actually received into the ion optics of the mass spectrometers downstream of the ion transfer channel.

[0005] It has been observed (see, e.g., Sunner et. al, J. Amer. Soc. Mass Spectrometry, V. 5, No. 10, pp. 873-885 (October 1994)) that a substantial portion of the ions entering the ion transfer tube are lost via collisions with the tube wall. This diminishes the number of ions delivered to the mass analyzer and adversely affects instrument sensitivity. Furthermore, for tubes constructed of a dielectric material, collision of ions with the tube wall may result in charge accumulation and inhibit ion entry to and flow through the tube. The prior art contains a number of ion transfer tube designs that purportedly reduce ion loss by decreasing interactions of the ions with the tube wall, or by reducing the charging effect. For example, U.S. Pat. No. 5,736,740 to Franzen proposes decelerating ions relative to the gas stream by application of an axial DC field. According to this reference, the parabolic

velocity profile of the gas stream (relative to the ions) produces a gas dynamic force that focuses ions to the tube centerline.

[0006] Other prior art references (e.g., U.S. Pat. No. 6,486,469 to Fischer) are directed to techniques for minimizing charging of a dielectric tube, for example by coating the entrance region with a layer of conductive material connected to a charge sink.

[0007] Another approach is to “funnel” ions entering from atmosphere towards a central axis. The concept of an ion funnel for operation under vacuum conditions after an ion transfer capillary was first set out in U.S. Pat. No. 6,107,628 and then described in detail by Belov et al in J Am Soc Mass Spectrom 200, Vol 11, pages 19-23. More recent ion funneling techniques are described in U.S. Pat. No. 6,107,628, in Tang et al, “Independent Control of Ion transmission in a jet disrupter Dual-Channel ion funnel electrospray ionization MS interface”, Anal. Chem. 2002, Vol 74, p 5431-5437, which shows a dual funnel arrangement, in Page et al, “An electrodynamic ion funnel interface for greater sensitivity and higher throughput with linear ion trap mass spectrometers”, Int. J. Mass Spectrometry 265 (2007) p 244-250, which describes an ion funnel adapted for use in a linear trap quadrupole (LTQ) arrangement. Unfortunately, effective operation of ion funnel extends only up to gas pressures of approximately 40 mbar, i.e 4% of atmospheric pressure.

[0008] A funnel shaped device with an opening to atmospheric pressure is disclosed in Kremer et al, “A novel method for the collimation of ions at atmospheric pressure” in J. Phys D: Appl Phys. Vol 39 (2006) p 5008-5015, which employs a floating element passive ion lens to focus ions (collimate them) electrostatically. However, it does not address the issue of focusing ions in the pressure region between atmospheric and forevacuum.

[0009] Still another alternative arrangement is set out in U.S. Pat. No. 6,943,347 to Willoughby et al., which provides a stratified tube structure having axially alternating layers of conducting electrodes. Accelerating potentials are applied to the conducting electrodes to minimize field penetration into the entrance region and delay field dispersion until viscous forces are more capable of overcoming the dispersive effects arising from decreasing electric fields. Though this is likely to help reducing ion losses, actual focusing of ions towards the central axis would require ever increasing axial field which is becomes technically impossible at low pressures because of breakdown.

[0010] Yet other prior art references (e.g., U.S. Pat. No. 6,486,469 to Fischer) are directed to techniques for minimizing charging of a dielectric tube, for example by coating the entrance region with a layer of conductive material connected to a charge sink.

[0011] While some of the foregoing approaches may be partially successful for reducing ion loss and/or alleviating adverse effects arising from ion collisions with the tube wall, the focusing force is far from sufficient for keeping ions away from the walls, especially given significant space charge within the ion beam and significant length of the tube. The latter requirement appears from the need to desolvate clusters formed by electrospray or APCI ion source. In an alternative arrangement, the tube could be replaced by a simple aperture and then desolvation region must be provided in front of this aperture. However, gas velocity is significantly lower in this region than inside the tube and therefore space charge effects produce higher losses. Therefore, there remains a need in the