METHOD AND APPARATUS FOR DIRECTING IONS AND OTHER CHARGED PARTICLES GENERATED AT NEAR ATMOSPHERIC PRESSURES INTO A REGION UNDER VACUUM

This invention was made with Government support under Contract DE-AC06-76RLO 1830 awarded by the U.S. Department of Energy. The Government has certain rights in the invention.

FIELD OF THE INVENTION

The present invention relates generally to a method and apparatus for directing or focusing dispersed charged particles into a variety of analytical apparatus in the presence of a gas. More specifically, the invention allows a dispersion of charged particles generated at or near atmospheric pressure to be effectively transferred into a region under vacuum.

BACKGROUND OF THE INVENTION

A great variety of scientific inquiry is confronted with the challenge of identifying the structure or composition of particular substances. To assist in this identification, a variety of schemes have arisen which require the ionization of the particular substance of interest. This need spans all charged particles including subatomic particles, small ions, and charged particles and droplets exceeding a micron in diameter.

In many such ion generating schemes, the presence of a gas or air is either essential to the ionization process or is an unavoidable consequence of the process. For example, in some cases, the ion current is measured, generally as a function of time, to assist in the identification, as in ion mobility analysis, or with thermal, flame or photoionization detectors used in conjunction with gas chromatography separations.

Charged particles beams are also used in ion guns, ion implanters, laser ablation plumes, and various mass spectrometers (MS), including quadrupole MS, time of flight MS, ion trap MS, ion cyclotron resonance MS, and magnetic sector MS. In mass spectrometry applications, typical arrangements often combine the charged particles or analyte with a carrier gas in an electrical field, whereupon particles are ionized by one method or another (e.g., inductive charging of particles) for use in an analytical process.

Many of these analytical techniques, as well as the other industrial uses of charged particles, are carried out under conditions of high vacuum. However, many ion sources, particularly sources used in MS and other analytical applications, operate at or near atmospheric pressures. Thus, those skilled in the art are continually confronted with challenges associated with transporting ions and other charged particles generated at atmospheric or near atmospheric pressures, and in many cases contained within a large gas flow, into regions maintained under high vacuum.

An illustrative example of this general problem is presented in the use of mass spectrometry as an analytical technique. In many applications of mass spectrometry, a charged particle or ion beam is generated at a higher pressure, for example, approximately atmospheric pressure in the case of electrospray ionization, and is then passed to a region maintained at a much lower pressure where the mass spectrometer can function effectively. In such an arrangement, the charged particle beam is directed through at least one small aperture, typically less than 1 mm diameter, which is used to maintain the pressure differential. Several stages of differential pumping are often used to create large pressure differences, and thus each of the regions are connected in series through apertures in order to allow gas flow into the lower pressure region.

Because of the dispersion of the charged particle beam, and the limited cross section defined by the aperture, a significant portion of the beam is typically unable to pass through each aperture and is thus lost. In many applications, a portion of the beam which is lost includes ions of interest, and may thus result in a decrease in the sensitivity of the analytical device. This can serve to preclude many analytical applications. Also, a loss of a portion of the beam may result in a disproportionate loss of the ions of analyte because the ions of analyte may not be evenly distributed throughout the charged particle beam.

In other uses of charged particles, it may be desirable to direct or collect dispersed charged particles which have not been generated as part of an charged particle beam per se. For example, in an atmospheric charged particle sampling device, it may be desirable to sample a large volume of air for the presence of some charged particles of interest. These charged particles may be ambient, or produced by photoionization or other means. It would be useful to have a means by which charged particles in the air are captured and directed to a detector, collector or other devices. Examples of possible uses include environmental monitoring for releases of ambient ions, aerosols, and other ion-producing processes such as combustion.

To assist in the transfer of ions and other charged particles at lower pressures, the use of DC electrical (electrostatic) fields, generated by a variety of methods, for the manipulation of charged particles or to assist in the collection of charged particles, is well known in the art. In ion sources operated at higher pressures, an unavoidable consequence is the presence of gas phase collisions and charge-charge repulsion interactions that lead to expansion of the ion cloud. Conventional ion optics devices such as electrostatic devices, which can function effectively to focus ions under vacuum conditions, are ineffective for avoiding or reversing the ion cloud expansion brought about by gas phase collisions and the repulsive electrical forces between charged particles. Also, time varying (electrodynamic) or radiofrequency (RF) electric fields can be applied for focusing purposes. An example of such RF devices are RF multipole devices in which an even number of rods or "poles" are evenly spaced about a line that defines the central axis of the multipole device. These include quadrupole, hexapole, octopole and "n-pole" or greater multipole devices that are used for the confinement of charged particles in which the phase of the RF is varied between adjacent poles. The use of these devices can result in focusing of an ion beam due to collisional damping in the presence of a gas as described in U.S. Pat. No. 4,963,736 to D. J. Douglas entitled "Mass Spectrometer and Method with Improved Ion Transmission" and U.S. Pat. No. 5,179,278 to D. J. Douglas entitled "Multipole Inlet System for Ion Traps." It is generally recognized that RF multipole devices can be used to trap or confine charged particles when operated at appropriate RF frequencies and amplitudes. In such arrangements, the motion of charged particles of appropriate mass and charge is constrained by the effective repulsion (of the "pseudo potential") arising from the RF field near the electrodes (poles). The charged particles thus tend to be repulsed from the region near the electrodes and tend to be confined to the inner region which is relatively field free. Thus, for example, in quadrupole devices, which are typically operated in high vacuum, ions tend to oscillate within the area inscribed by