RF MULTIPOLE ION GUIDES FOR BROAD MASS RANGE

BACKGROUND

[0001] The invention relates to multipole systems which are operated with RF voltages and are used as ion guides to collect or transmit ions.

[0002] RF multipole rod systems have been used as ion guides for more than twenty years. Particularly well known are RF quadrupole rod systems with four pole rods according to Wolfgang Paul, but hexapole and octopole rod systems are also quite popular. The rod systems can be made of round pole rods but hyperbolic rods are more favorable, especially for quadrupole rod systems.

[0003] The multipole systems are based on the effect of so-called "pseudopotentials", which are produced in inhomogeneous alternating fields. Both the alternating field at the tip of a wire, whose field intensity decreases with $1/r^2$, as is well known, and also the alternating field around a long wire, which decreases with $1/r$, reflect both positively and negatively charged particles. This occurs because the particle oscillates in the alternating field of the wire. Irrespective of its charge, the particle experiences maximum repulsion from the wire precisely when it is at the point of its oscillation which is closest to the wire, i.e. at the point where the field intensity is highest; the particle experiences maximum attraction when it is furthest away, i.e. at the point of its oscillation where the field intensity is lowest. Integration over time therefore gives a repulsion of the particle away from the tip. The repulsive field obtained by integration over time can be described by the "pseudopotential" which is proportional to the square of the alternating field intensity. The derivative of this gives an electric "pseudo force field". For the tip of the wire, the repulsive pseudopotential decreases at $1/r^4$; for the long wire it decreases outward at $1/r^2$, but in both cases it is still inversely proportional to the mass of the ions and the square of the frequency.

[0004] If the two opposite phases of an RF voltage are applied to two neighboring wire tips, then both tips repel charged particles independently. Their combined effect is amplified. The alternating field of this dipole already decreases at more than $1/r^2$, however. If one arranges a complete two-dimensional field of wire tips where different phases of the RF voltage are applied to neighboring tips in both dimensional directions, a surface is obtained which repels particles of both polarities at short range and hence reflects them. This is not a specular but a diffuse reflection. In front of this field, at a distance which is large compared to the separation of the tips, there is almost no field at all.

[0005] The field produced by long, parallel wires also forms an ion reflector if every other wire is fed one phase of the RF voltage and the remaining wires the other phase. A mixture of tips and wires, similar to a mesh, is also possible, in which case there is a wire tip in each cell of the mesh.

[0006] The surface made up of parallel wires also produces an alternating field which is effective only a short distance into the space outside the surface. In the longitudinal direction of the wires, the reflection is specular; in the transverse direction it is diffuse. With an infinitely extended surface, the field decreases roughly exponentially in the direction perpendicular to the surface. If there is a field intensity F on the surface of a wire grid, whereby the radius of the wires is one tenth of the separation of the wires, then at a distance of one wire separation, the field intensity is only 5% of F; at a distance of two wire separations it is only 0.2% of the field intensity F; at a distance of three wire separations it is only 0.009% of the field intensity F. The repulsive pseudopotential, which is proportional to the square of this field intensity, thus decreases even more rapidly.

[0007] The reflective effect that RF voltages have on bipolar grids made of tips or wires has already been described in U.S. Pat. No. 5,572,035A (J. Franzen). The multipole rod systems are limiting cases of reflective walls based on parallel wires where the wires form a cylindrical wall.

[0008] If one considers the pseudopotential in the cross section of a quadrupole rod system, it has a minimum in the axis of the rod system. The pseudopotential increases quadratically from the axis outward on all sides. The rotationally symmetric parabolic minimum of the pseudopotential in the cross section forms a potential channel along the axis of the rod system. If a rod system such as this is filled with a collision gas at a pressure between 0.01 and 1 Pascal, injected ions give up most of their kinetic energy as a result of collisions with this gas and collect with only thermal energy in this potential channel along the axis. This effect is also observed when the ions are in slow flight. This process, which has been known since the early 1980s, is now termed "collisional focusing".

[0009] Collisional focusing is now of significant importance for most modern mass spectrometers. The injection of ions into a subsequent stage of a mass spectrometer, for example into a subsequent ion guide or ion analyzer, almost always depends on the cross section of the ion beam. A very fine beam cross section, as is produced by collision focusing, is almost always advantageous. This applies for injection into a quadrupole mass filter just as it does for injection into an ion trap, and in particular for injection into a time-of-flight mass spectrometer with orthogonal ion outpulsing into the flight path.

[0010] The rod systems used to guide ions are generally very long and thin so that they can concentrate the ions in a region with a very small diameter. They can then be advantageously operated with low RF voltages and form a good starting point for the subsequent ion-optical imaging of the ions. The free cylindrical interior is often only around 2 to 4 millimeters in diameter, the rods are less than one millimeter thick, and the system is 2 to 25 centimeters long. The term "long" pole rods here should be taken to mean pole rods which are longer than the separation between opposite pole rods.

[0011] The term "mass" here always refers to the "mass-to-charge ratio" or "charge-related mass" m/z, which alone is of importance in mass spectrometry, and not simply to the "physical mass" m. The number z indicates the number of elementary charges, i.e. the number of excess electrons or protons of the ion, which act externally as the ion charge. All mass spectrometers without exception can measure only the mass-to-charge ratio or charge-related mass m/z, not the physical mass m itself. The mass-to-charge ratio is the mass fraction per elementary charge of the ion.

[0012] It is known that all RF rod systems exhibit a lower mass limit for the storage or transmission of ions. In