Development of an Ion Trap Mass Spectrometer with an Alternate Trapping Geometry

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Ion-ion interactions (space charge) limit the performance of ion trap mass spectrometers under conditions of high ion currents. This problem is manifested in many areas of ion trap operation[1] but most commonly as a maximum dynamic range of approximately 10^4. Attempts to mitigate space charge effects have included coincident trapping of both positive and negative ions[2] but this approach typically requires multiple ion sources. Efforts to make the trapping field larger (increased radius, r_0) to accommodate an increased number of ions are limited by the fundamental equations where the ring rf voltage (V) is proportional to the square of the ring radius (r_0). Current rf power supplies are already near the plasma discharge limit at voltages approaching 15000 V_{p-p}. These same fundamental limitations affect attempts to develop smaller ion trap devices that would operate on considerably less rf power since onset of space-charged conditions will occur at much lower ion concentrations in these smaller devices.

We have been developing an ion trap with a radically different analyzer design to address both space charge limitations as well as smaller, lower power ion trap instruments. This new geometry can allow a dramatic increase (10^2-10^3) in the ion storage volume of the trap. This geometry is based on rotation of the standard ion trap cross-section along an axis at the edge of the ring electrode as shown in Figure 1. This geometry (toroidal) is in contrast to a similar device, which is based on the cyclization of linear quadrupole[3]). The toroid ion trap uses a standard ITMS electronic system with a custom vacuum chamber. Since the r_0 of the device is 1 cm (same as the standard Finnigan ITMS), there are only minimal changes required to the operating electronics of the instrument (retapping of the rf coil and modification of the rf drive frequency from 1.1 MHz to 976 kHz). SIMION 3D6 was used to simulate the device's ability to trap ions formed from a point source, allow time for diffusion and then kinetically cool them to the center of the device as shown in Figure 2. Current performance of the toroid ion trap gives mass resolution of ca. 1-2 da. FWHM as is shown in the spectrum for benzene (Figure 3). The device performance (both intensity and mass resolution) is extremely sensitive to pressure and β_{eject}-values with the optimum at 3 x 10^{-6} torr and 0.39, respectively. The origins of the performance limitation are currently under study.

The toroid ion trap can be configured in a smaller version with similar ion storage volumes to a conventional ion trap but would operate on significantly reduced rf voltage. In addition, new modes of ion activation may be possible with this design that could have substantial impact on ion kinetic energies (and thus internal energy deposition) in MS/MS experiments.

FIGURE 1: Toroid Ion Trap Schematic Cross-Section

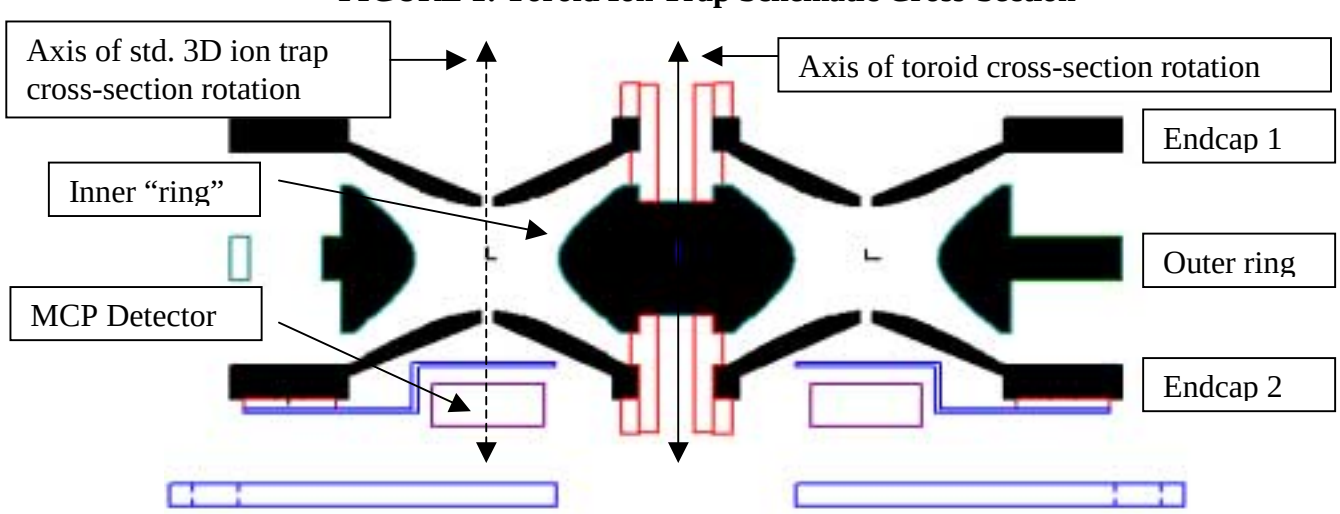


FIGURE 2: SIMION 3D6 Simulation of Toroid Geometry (axial view)

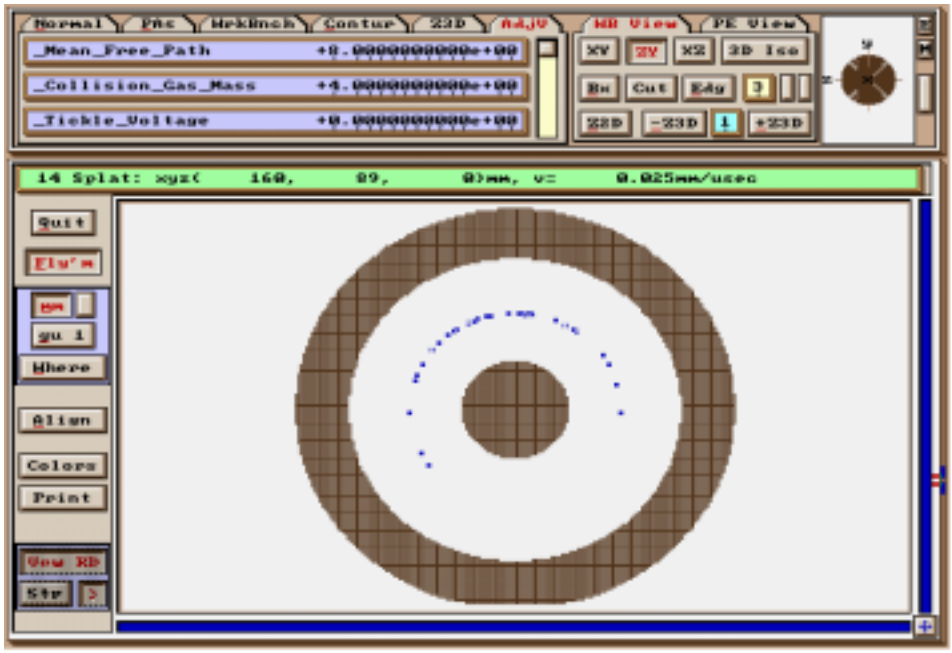
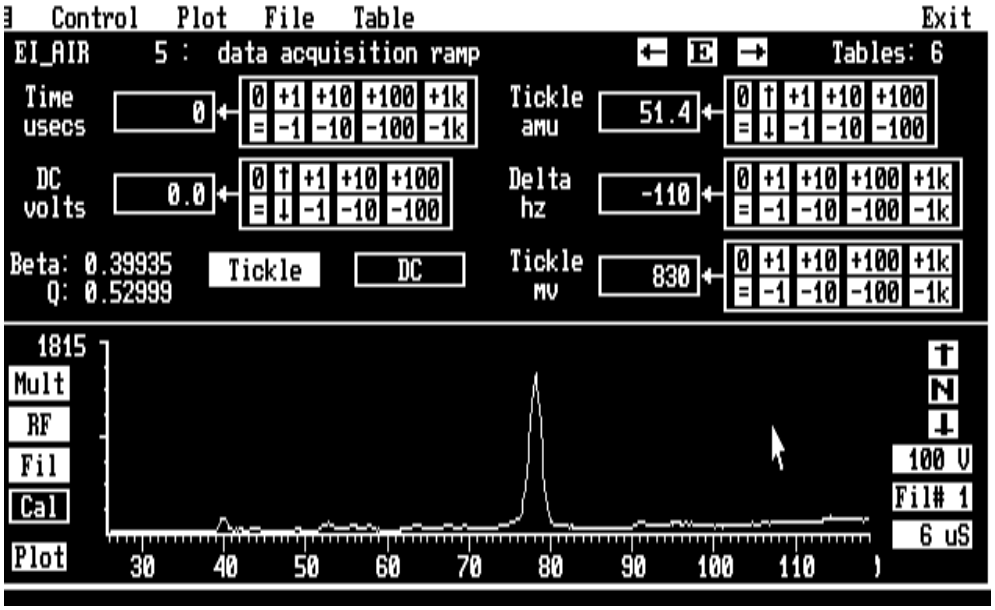


FIGURE 3: Benzene Spectrum



References

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