The Coaxial Ion Trap Mass Spectrometer: Concentric Toroidal and Quadrupolar Trapping/Analyzing Regions

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Abstract

We present the design and results for a new radiofrequency ion trap mass analyzer, the coaxial ion trap, in which both toroidal and quadrupolar trapping regions are created simultaneously. The device consists of two parallel ceramic plates, whose facing surfaces are lithographically patterned with concentric metal rings and covered with a layer of germanium. Ions can be trapped in either region, transferred from the toroidal region to the quadrupolar region, and mass-selectively ejected from the quadrupolar region to a detector. Ions trapped in the toroidal region can be transferred to the quadrupole region using an applied ac signal in the radial direction, although it appears that the mechanism of this transfer does not involve resonance with the ion secular frequency, and the process is not mass selective. Ions in the quadrupole trapping region are mass analyzed using dipole resonant ejection. Multiple transfer steps and mass analysis scans are possible on a single population of ions (as from a single ionization/trapping event), illustrating the larger ion capacity of the toroidal ion trap and possible applications in analyzing transient or dynamic events.

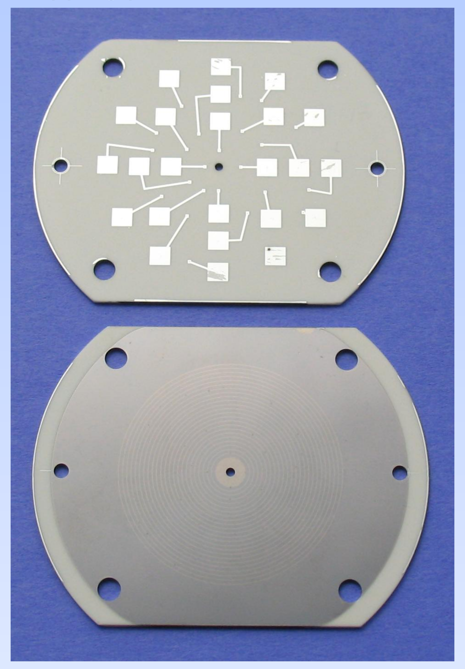
Trap Plate Design

Trap plates begin as alumina substrates, 0.65 mm thick and 46 mm diameter. Holes are laser drilled for vias (electrical connections between front and back sides) which are then filled with gold. Holes for ion ejection and for mounting are also laser drilled. Aluminum electrode rings are photolithographically deposited in the trapping side, and connections and contact pads are patterned on the backside. A thin layer of germanium is deposited on top of the rings on the trapping side.

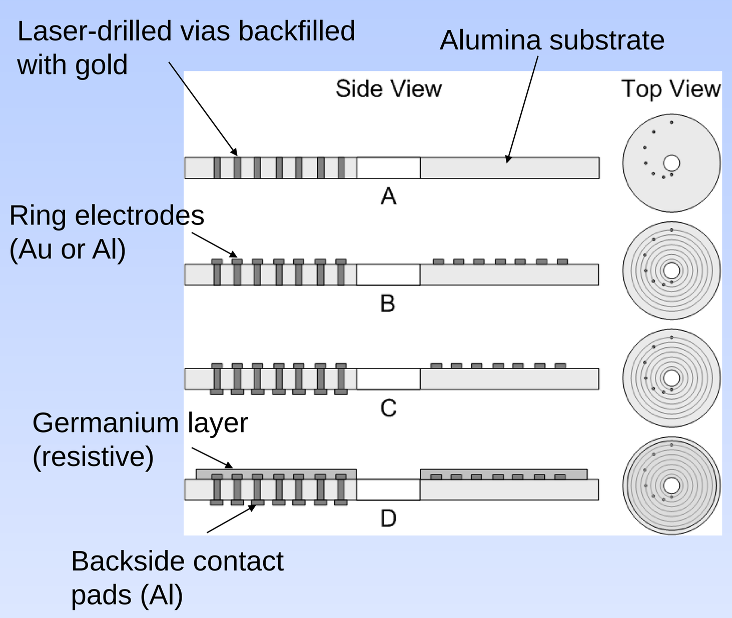
Potentials are applied to the trap using an RF power supply, and the potential on each ring is set using a capacitive voltage divider. Supplementary voltages (ac or dc) can be applied to specific rings, or to just one plate.

The germanium layer prevents build-up of charge on the surfaces, and also evens out the potential applied by the rings.

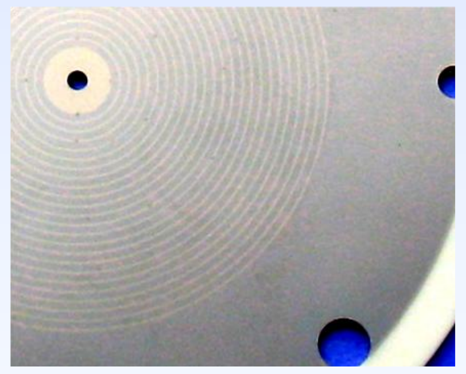
Trapping plates, front and back sides



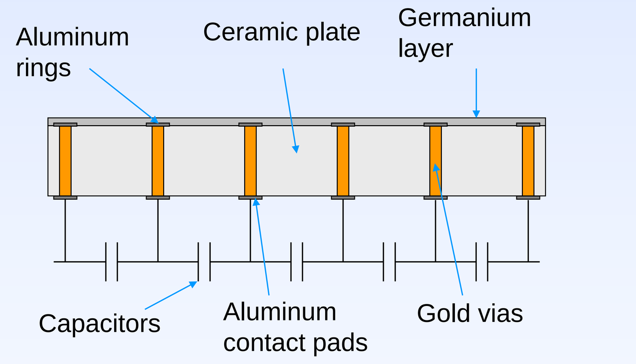
Fabrication and lithography steps to produce plates



Enlargement in which aluminum rings can be seen through the germanium

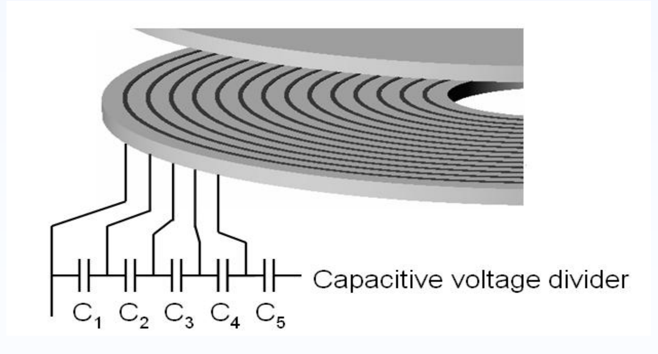


Cross section of plates and electrical connections



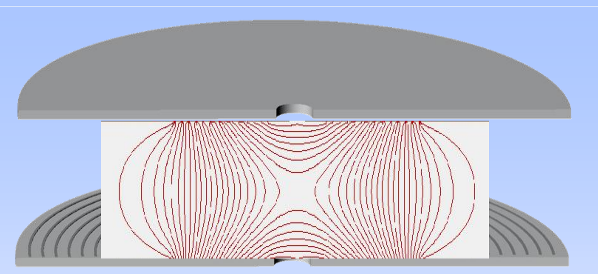
Assembled ion trap including ceramic plates, printed circuit boards, and metal spacer.

Arrangement of electrode rings, vias, and capacitive voltage divider

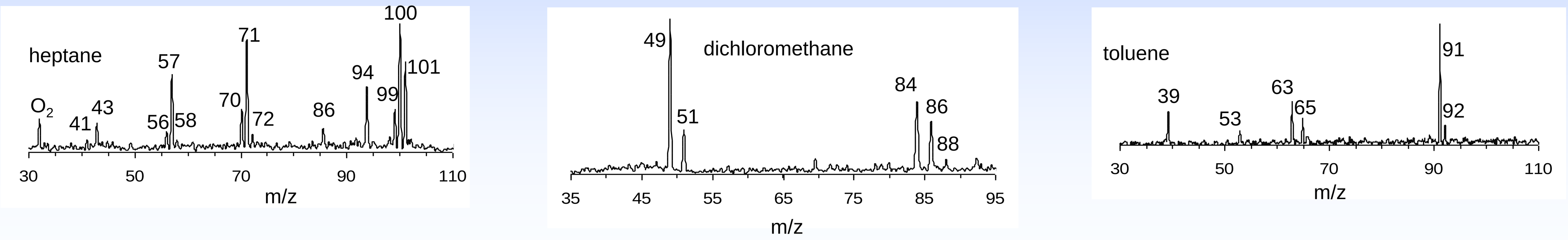


Two-plate Quadrupole Ion Trap

In previous work we developed and demonstrated a quadrupole ion trap (Paul trap) made using two plates. A 1-mm hole is used for ion ejection. The spacing between the plates is 5 mm, corresponding to a z_0 value of 2.5 mm. Shown at bottom are spectra of several organics taken using a dipole resonance ejection scan, with drive RF at 1.1 MHz, ramped from 250-750 V_{0-p}, operated using 1 mtorr of helium as buffer gas. The same plates and physical assembly are used to make the coaxial trap, just with different voltages applied to each electrode ring.

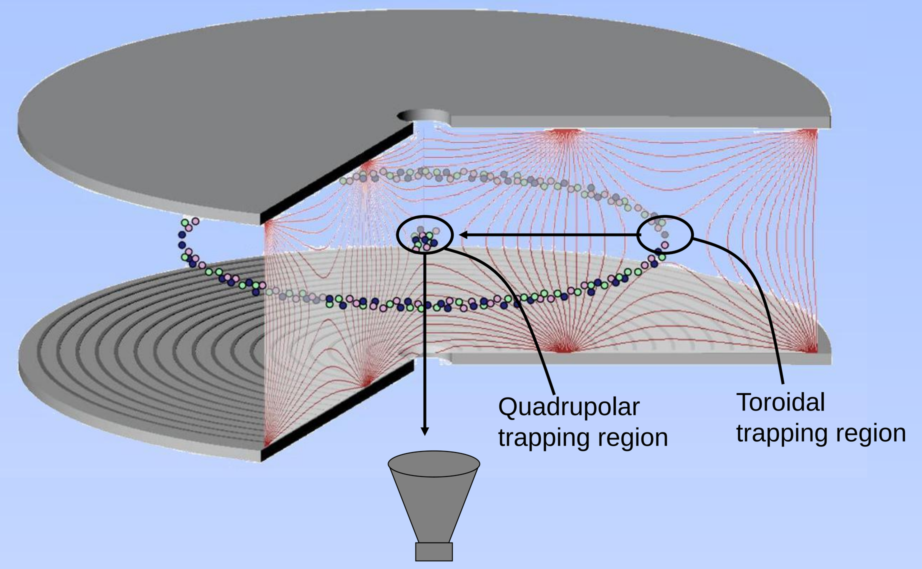


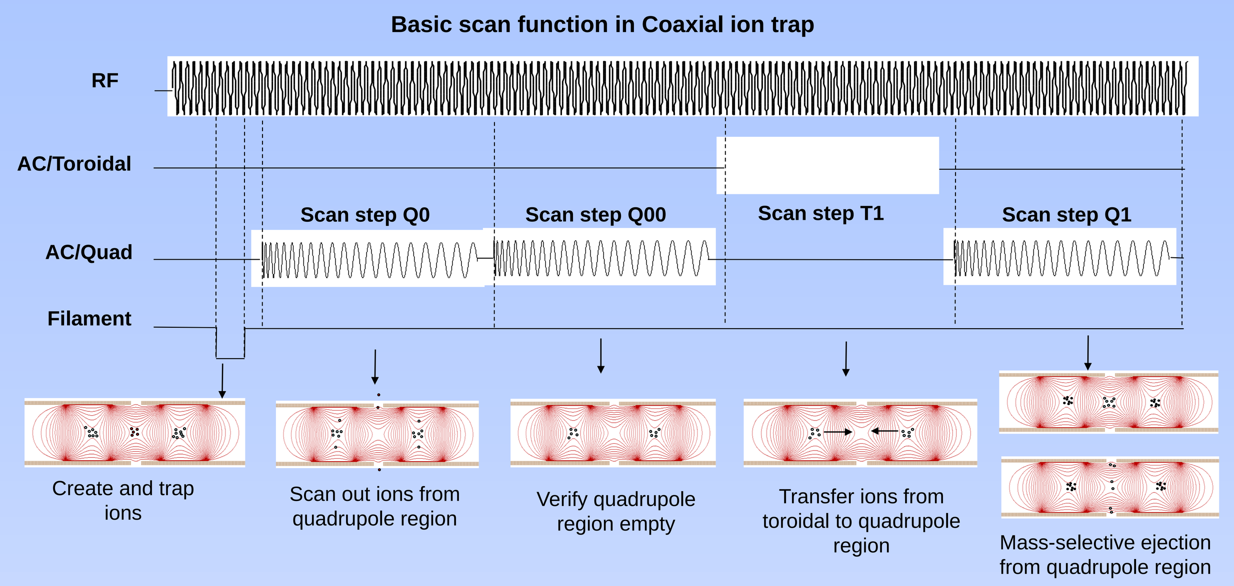
Typical mass spectra from the two-plate quadrupole ion trap (planar Paul trap). Characteristic peaks for each compounds are labeled.

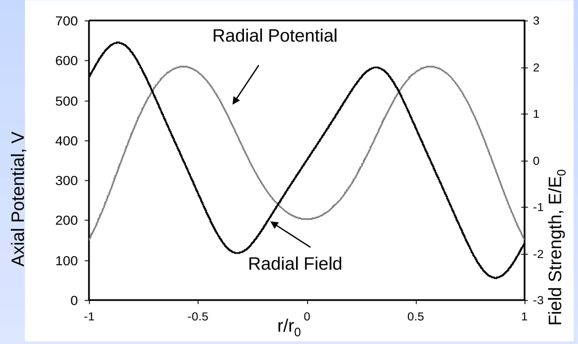


Coaxial Ion Trap

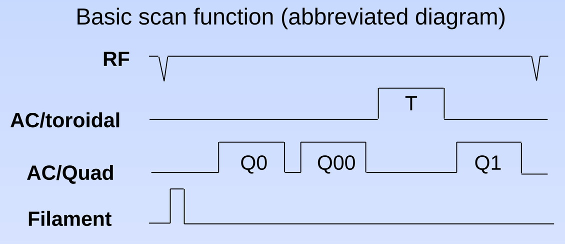
The Coaxial ion trap combines the quadrupolar trapping geometry of the planar Quadrupole ion trap and a toroidal trapping geometry. The coaxial ion trap is made using the exact same plates and physical assembly fabrication as the planar quadrupole trap, differing only in the RF amplitudes applied to each ring. Experiments demonstrate that ions can be trapped in either region, transferred from the toroidal to the quadrupolar region, and mass-selectively ejected from the quadrupolar region to a detector. Multiple transfer steps on the same population of ions has been shown to improve sensitivity and dynamic range of the coaxial ion trap compared with the two-plate quadrupole ion trap.

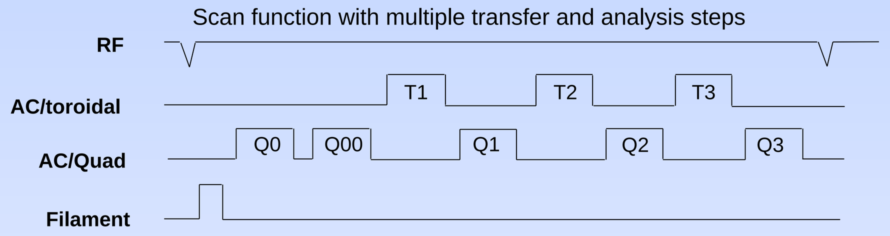


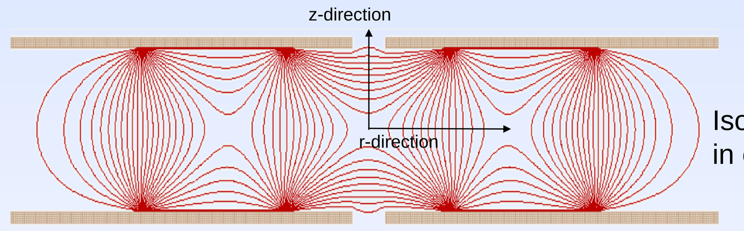




Radial potential and fields in coaxial ion trap

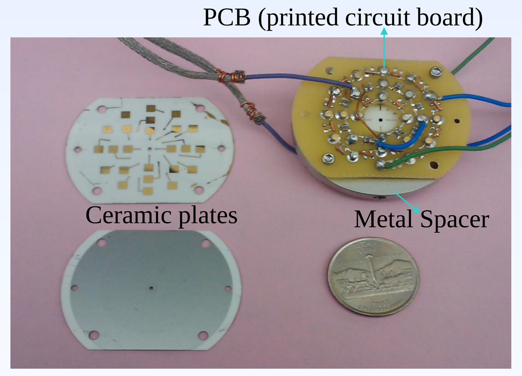




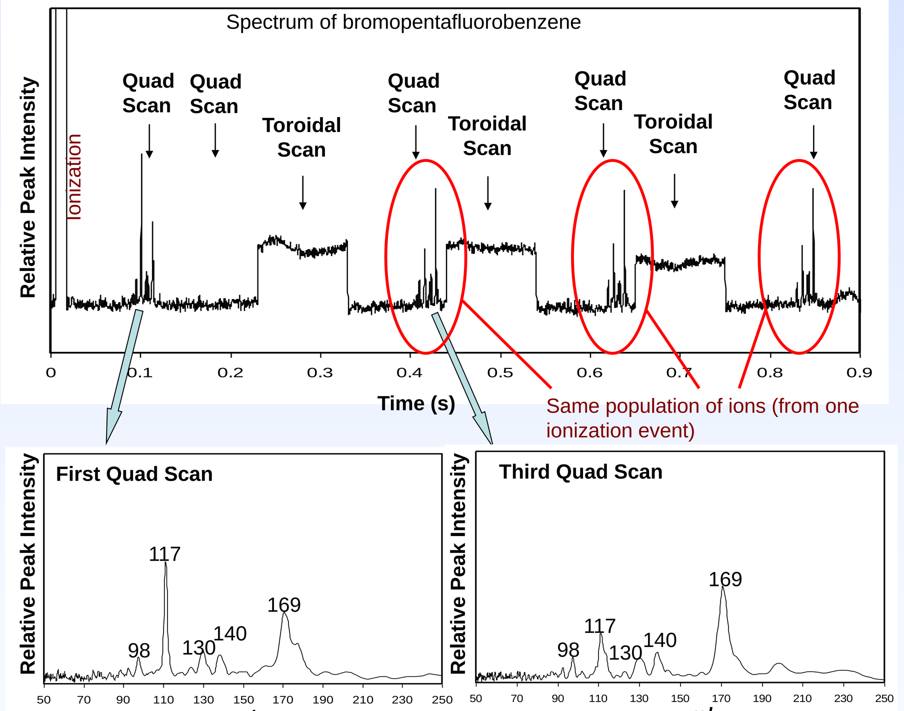


Isopotential contours in coaxial ion trap

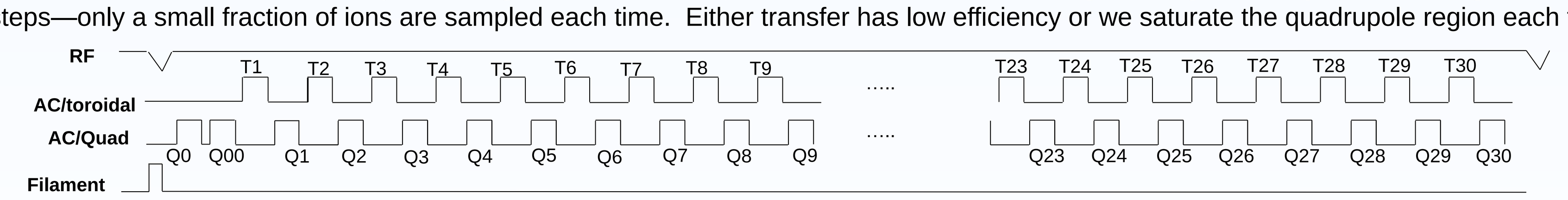
Plates and partial assembly of coaxial ion trap



Data from coaxial ion trap experiment with 3 transfer /analysis steps

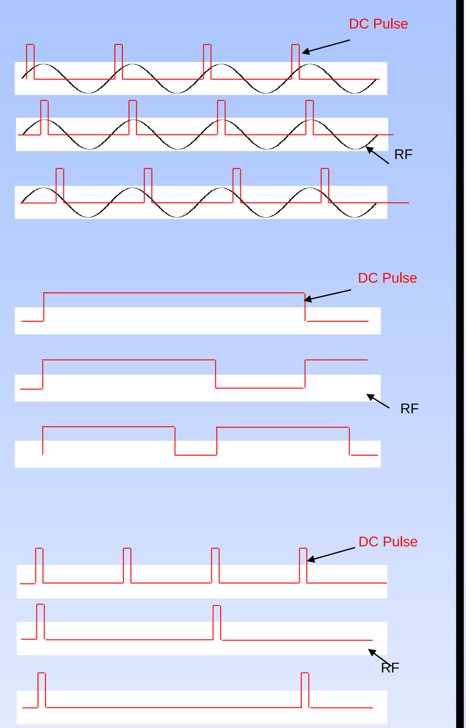


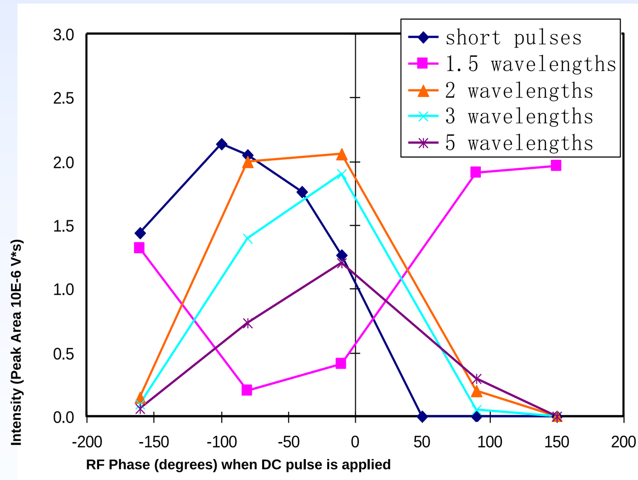
Many transfer steps on the same population of ions (from a single ionization event) was tested to demonstrate larger storage capacity of toroidal region. No loss in signal after 30 steps—only a small fraction of ions are sampled each time. Either transfer has low efficiency or we saturate the quadrupole region each time



Understanding Ion Transfer Mechanism

In preliminary experiments ion transfer from the toroidal region is not mass selective. All masses are transferred. Simulations show that mass-selective transfer is possible, but this has not been observed experimentally. We have carried out experiments to understand the mechanism of ion transfer. Instead of the ac signal used for transfer, DC pulses at different phases of the RF were used to "push" ions to the center. We are currently exploring electric field configurations that may allow mass-selective transfer.





Ion transfer depends on phase relationship between RF and AC

Conclusions

Making ion traps using two plates is a solution to the problem of making a 3-dimensional device using microfabrication, an inherently 2-dimensional fabrication technique. Surface features can be produced with high accuracy in 2 dimensions on each plate. Alignment of two plates is simpler than aligning the larger number of electrodes in conventional ion traps. The plates can be positioned at any distance from each other, allowing both full-sized and miniaturized devices to be made using the same technique. In addition, because the electric field is governed by the surface potential on each plate, it is possible using this approach to independently adjust the magnitudes of higher-order multipoles. Any trapping geometry can be realized using this approach; we have demonstrated miniaturized quadrupole, toroidal, and linear ion traps, as well as a combined trap, the coaxial trap, which combines both toroidal and quadrupolar trapping fields simultaneously.

Acknowledgement

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Relevant publications:

Peng, Y.; Austin, D.E. "New Approaches for Miniaturizing Ion Trap Mass Analyzers", *Trends in Analytical Chemistry*, **in press**.

Peng, Y.; Hansen, B.J.; Quist, H.; Zhang, Z.; Hawkins, A.R.; Austin, D.E. "Coaxial Ion Trap: Concentric Toroidal and Quadrupole Trapping Regions in One Mass Analyzer", *Analytical Chemistry*, **2011**, 83 (14) 5578-5584.

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Austin, D.E., M. Wang, S.E. Tolley, J.D. Maas, A.R. Hawkins, A.L. Rockwood, H.D. Tolley, E.D. Lee, M.L. Lee "Halo ion trap mass spectrometer" *Analytical Chemistry*, **2007**, 79, 2927-2932.