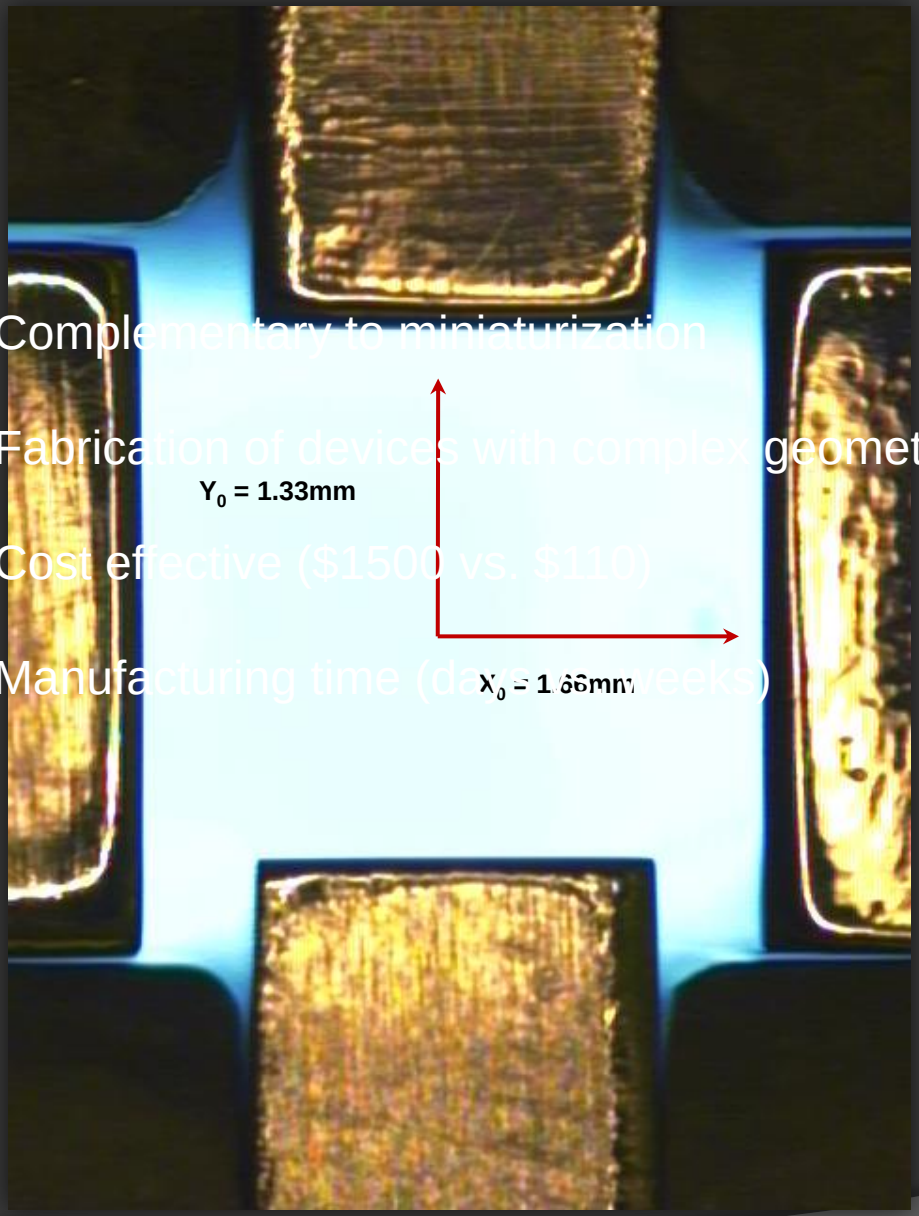
DEVELOPMENT OF A MINIATURE RECTILINEAR ION TRAP ARRAY WITH INDEPENDENTLY CONTROLLED CHANNELS

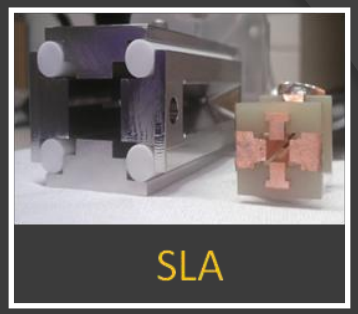
Paul Hendricks,[1] Jeff D. Maas,[2] William J. Chappell,[2] Rob Noll,[1] Zheng Ouyang,[3] R. Graham Cooks[1]

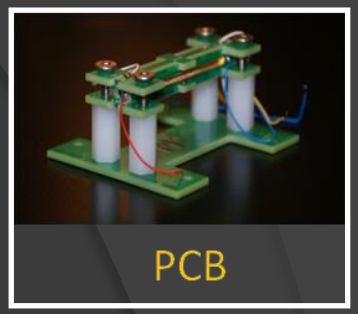
[1]Dept. of Chemistry, Purdue University, IN;
[2]Dept. of Electrical Engineering, Purdue University, IN;
[3]Dept. of Biomedical Engineering, Purdue University, IN

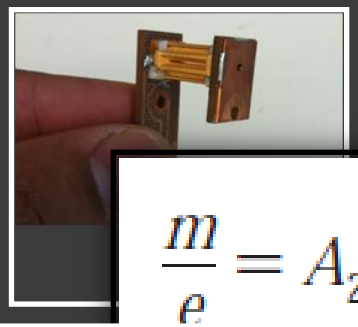
Mass analyzer miniaturization: Scale, RF, Fabrication Technologies, and Cost

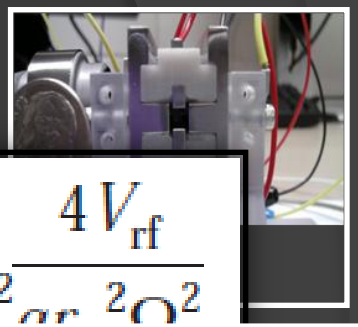


- Complementary to miniaturization
- Fabrication of devices with complex geometries
- Cost effective ($1500 vs. $110)
- Manufacturing time (days vs. weeks)









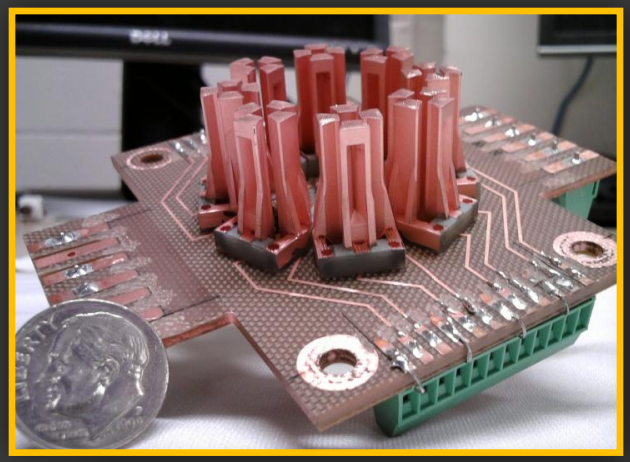
$$\frac{m}{e} = A_2 \frac{4\,V_{\mathrm{rf}}}{\omega r_0^2 \Omega^2}$$

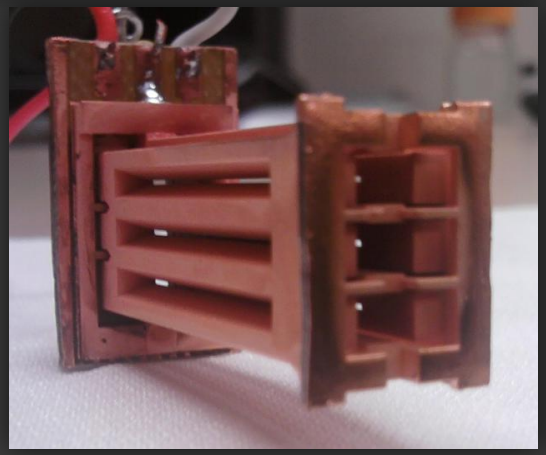
Large inductor for RF drive

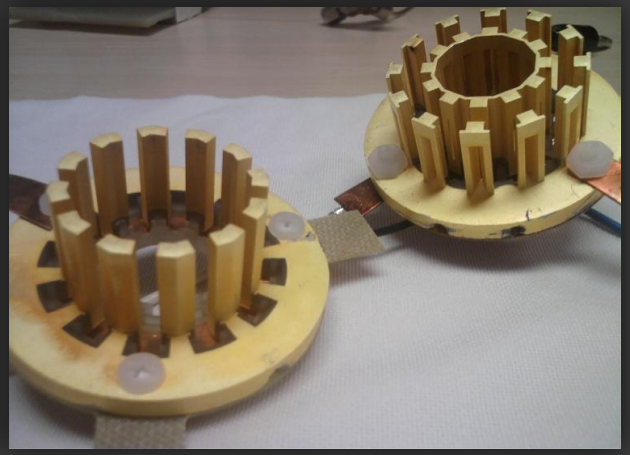
Small amplifier for RF drive

M. Fico, M. Yu, Z. Ouyang, R.G. Cooks, W.J. Chappell, Analytical Chemistry, 79 (2007) 8076-8082
Z. Ouyang, G. Wu, Y. Song, H. Li, W.R. Plass, R.G. Cooks, Analytical Chemistry, 76 (2004) 4595-4505

Arrays offset the effect of ion attenuation due to miniaturization







- Fabrication Technology: Stereolithography apparatus
- multiple RITs for increased ion capacity
- Geometrically complex electrode structures
  - Circular
  - Linear
- Fabrication flexibility
  - Monolithic construction
  - Independently isolated electrodes

M. Fico, J.D. Maas, S.A. Smith, A.B. Costa, Z. Ouyang, W.J. Chappell, R.G. Cooks, Analyst, 134 (2009) 1338-1347
J.D. Maas, P.I. Hendricks, Z. Ouyang, R.G. Cooks, W.J. Chappell, Journal of Microelectromechanical Systems, 19 (2010) 951-960

Stereolithography Apparatus (SLA) Fabrication

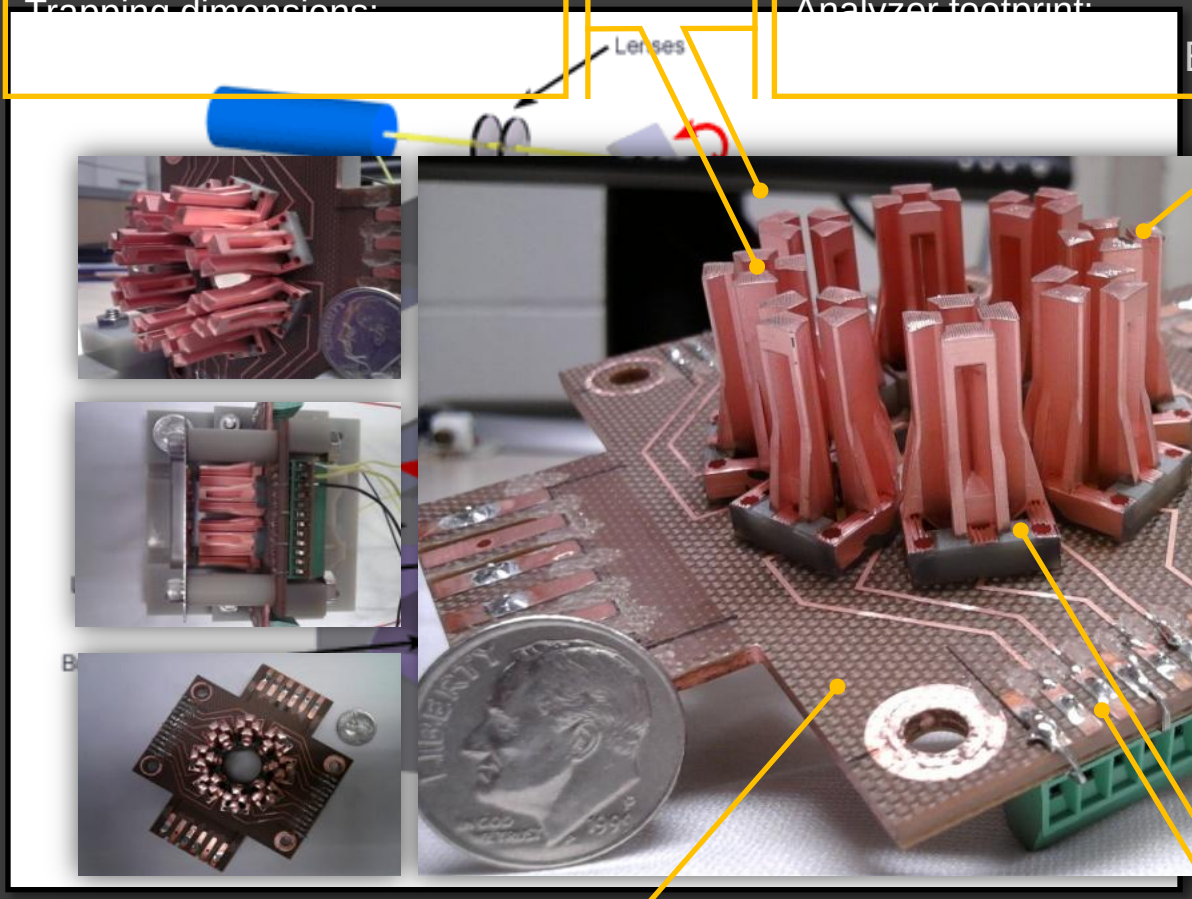
Trapping dimensions:

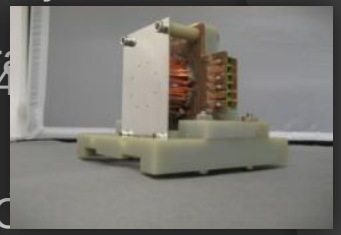
Analyzer footprint:

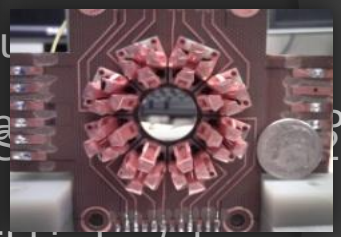
8 independent mass analyzers

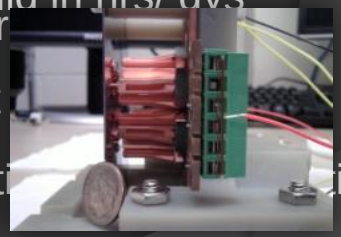
Base PCB substrate

Viper si2 SLA system









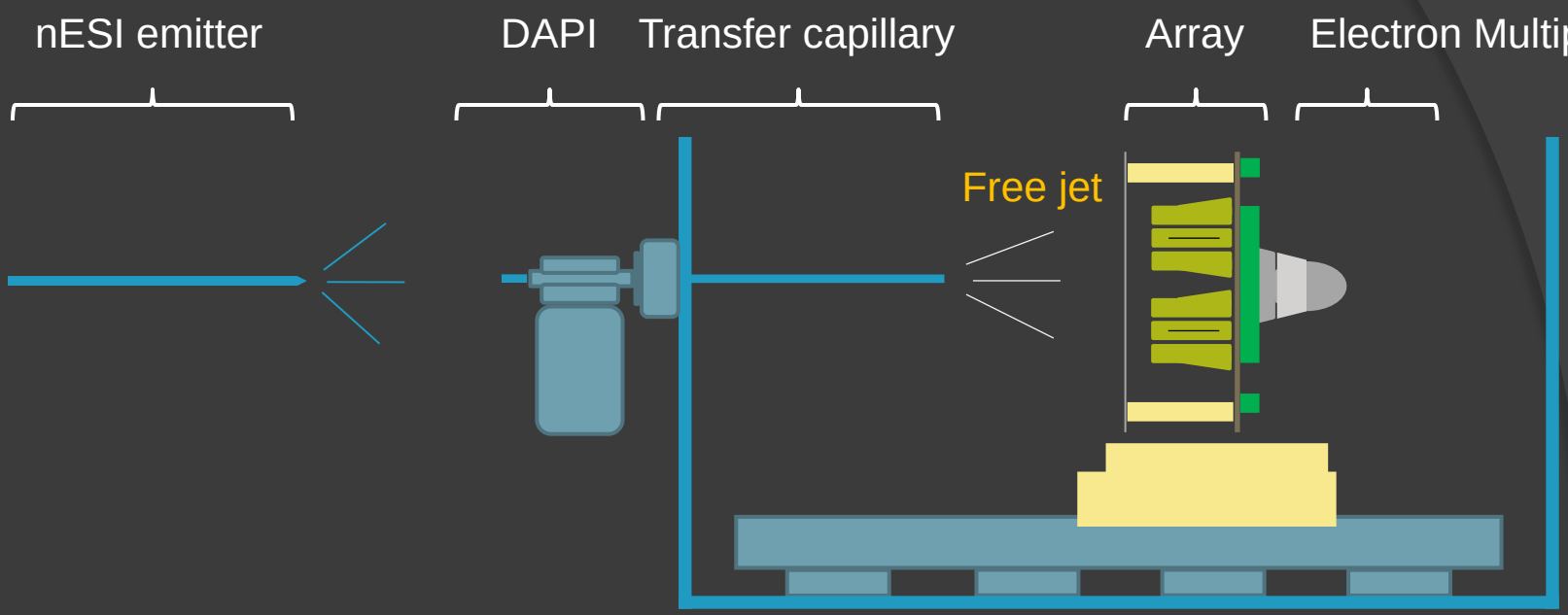
Monolithic, fully integrated analyzer

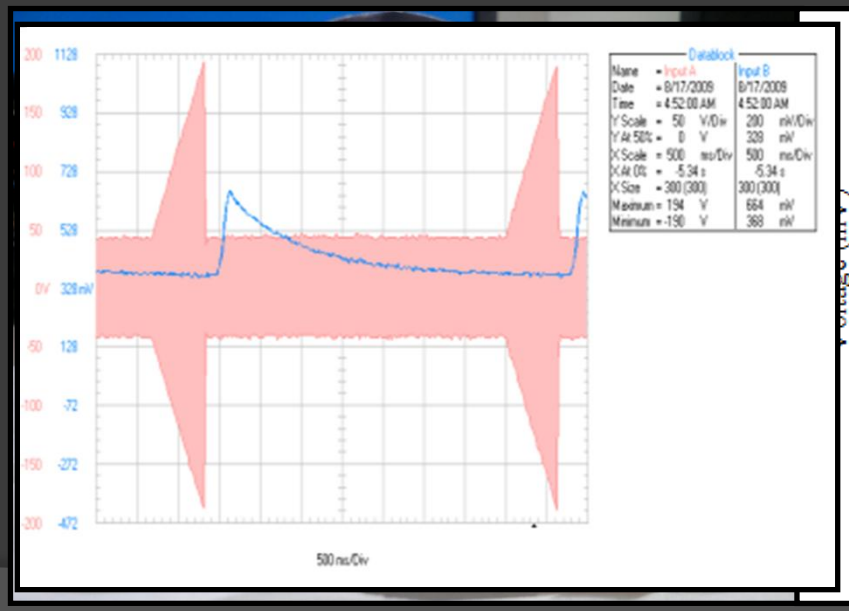
Additive Process

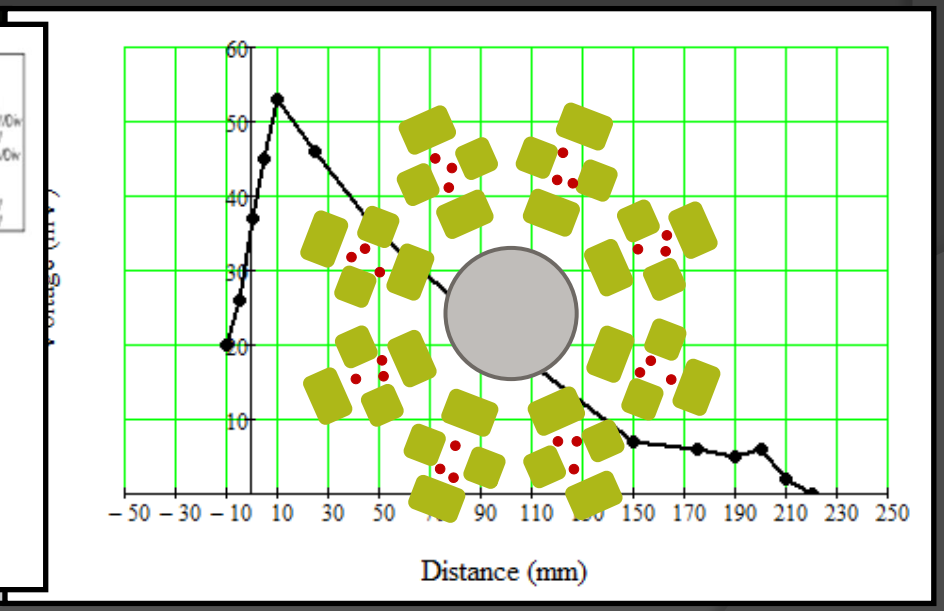
Flexible placement of electrodes & connections

Laser ablation used for electrode isolation

Array Operation and Control

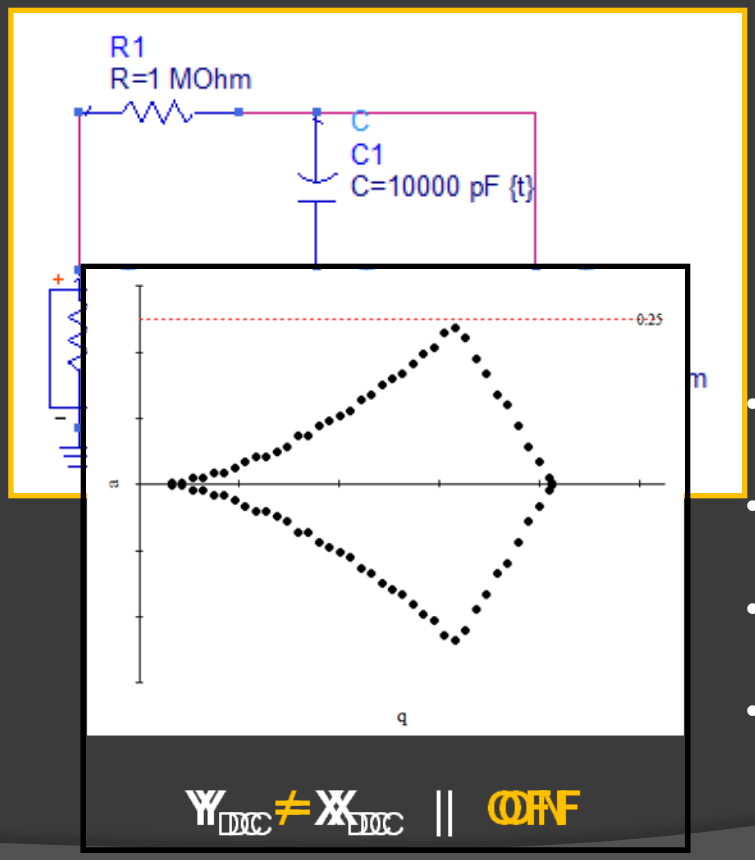






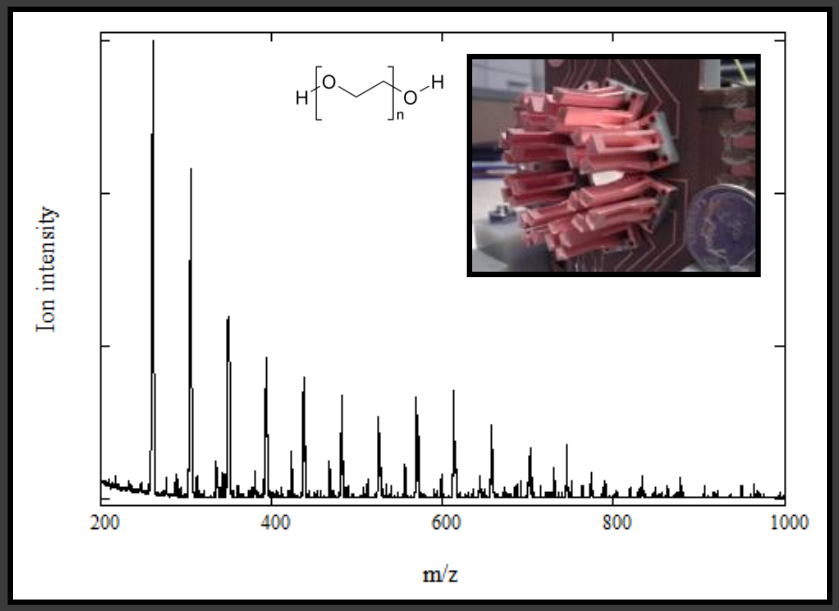
L. Gao, R.G. Cooks, Z. Ouyang, Analytical Chemistry, 80 (2008) 4026-4032

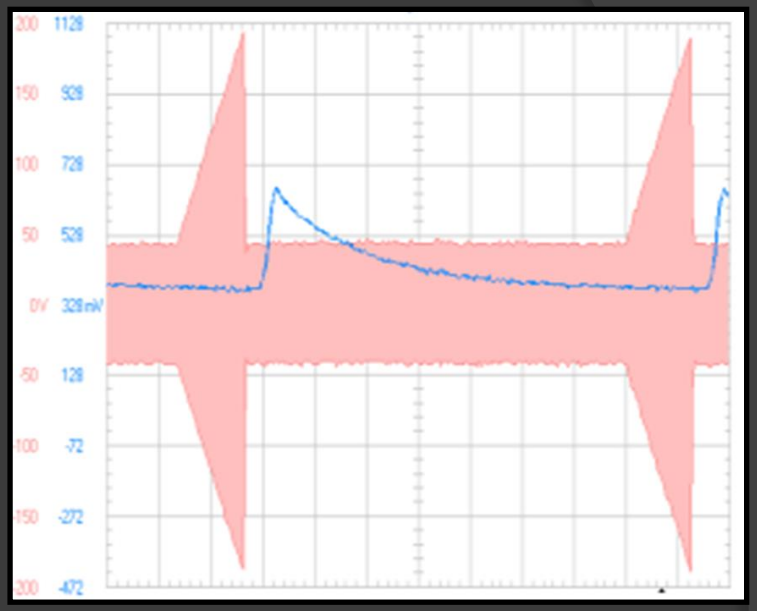
Array Operation and Control: Bias Tee as a On & Off Switch

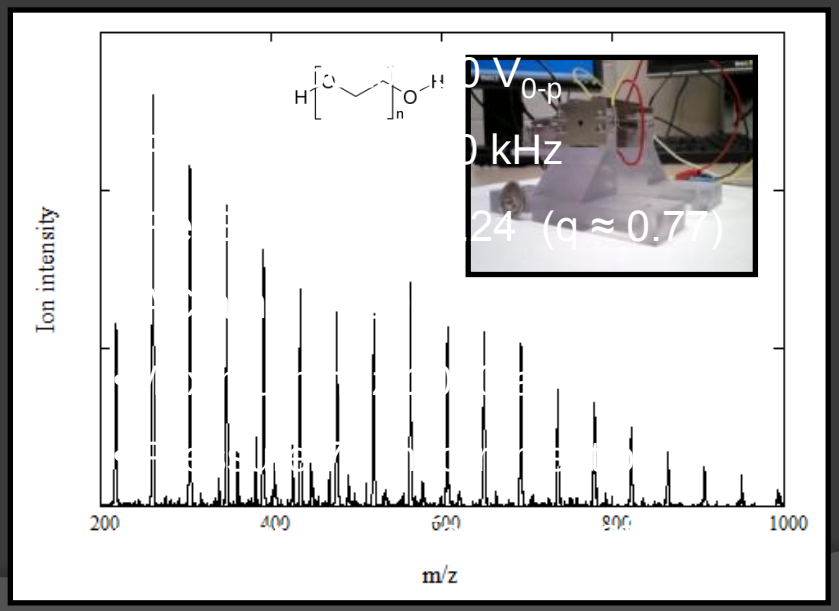


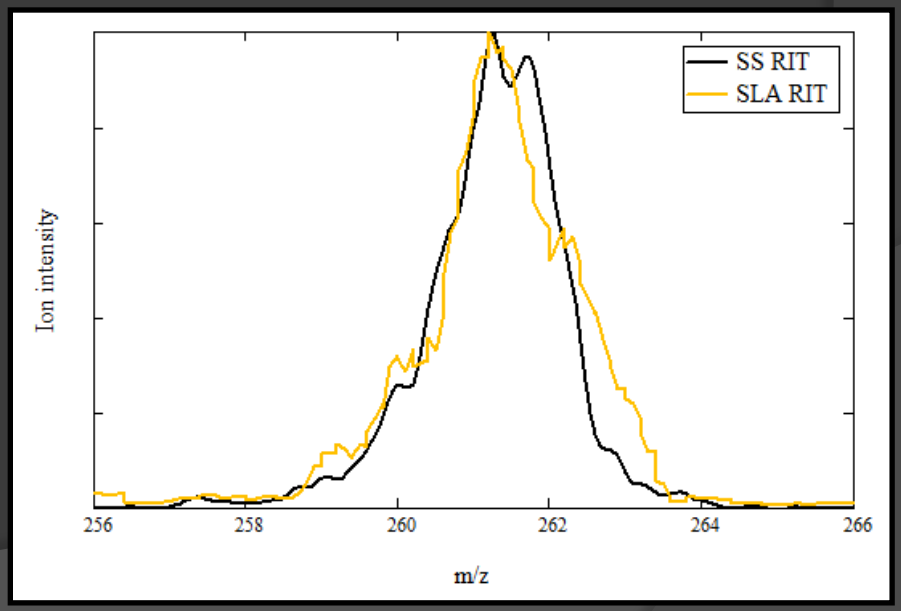
- Selective ion trap(s) operation inside the array
- Fast, reversible, and outside the vacuum chamber
- No physical obstruction to ion injection or detection
- RF voltages applied to all traps in the array

Performance: Full scan MS (SLA vs. SS RIT)



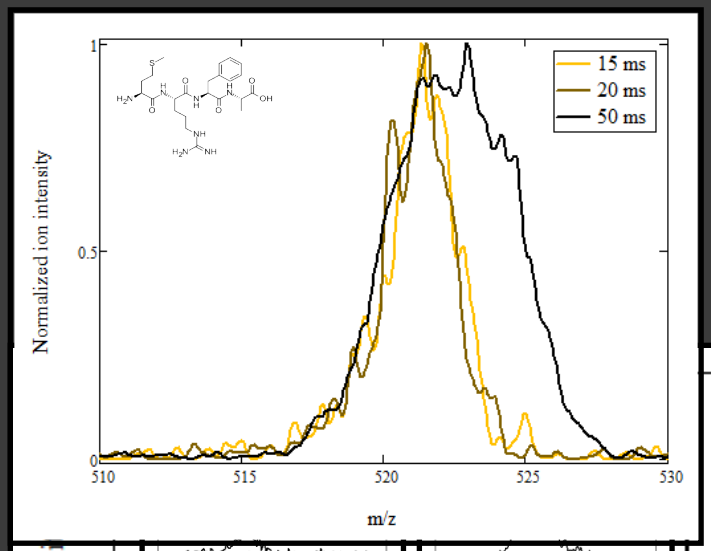


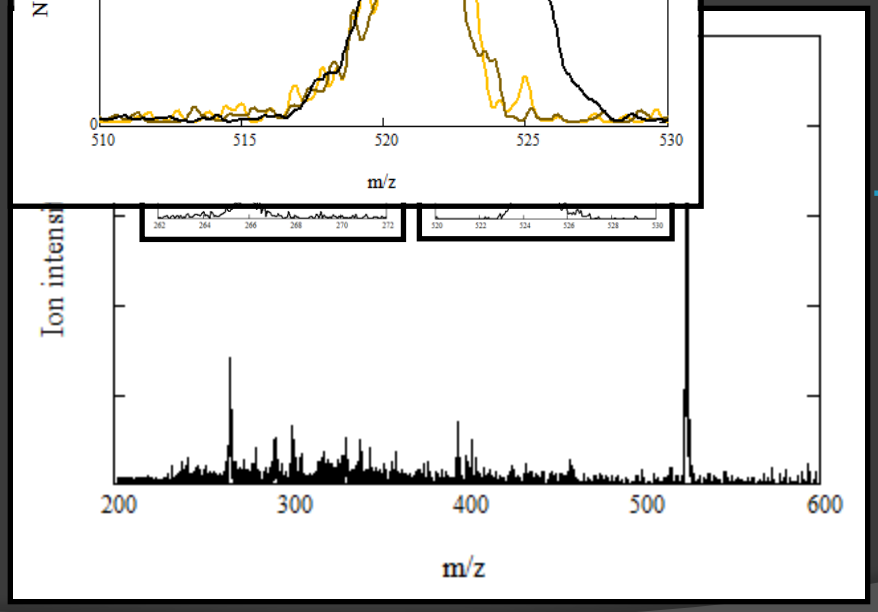


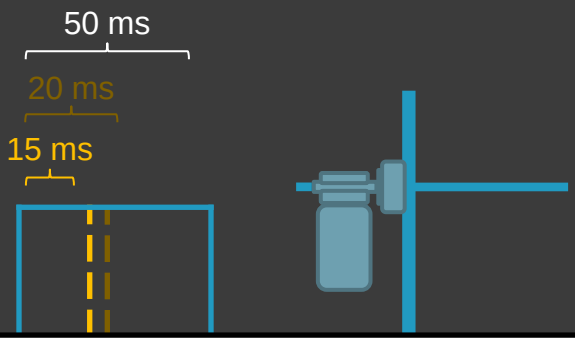


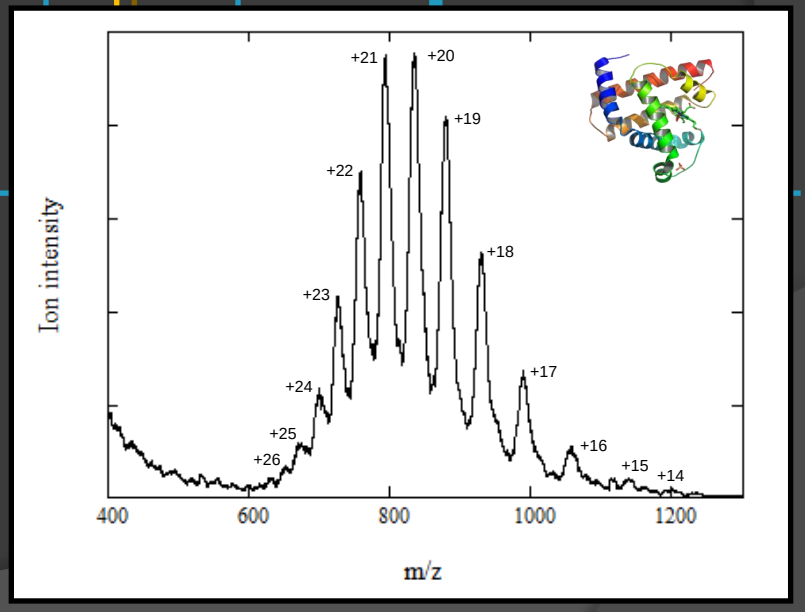
P. Hendricks, J. Duncan, R.J Noll, Z. Ouyang, International Journal of Mass Spectrometry, 305 69-73

Performance: Ion injection control, best resolution, and Intact protein analysis

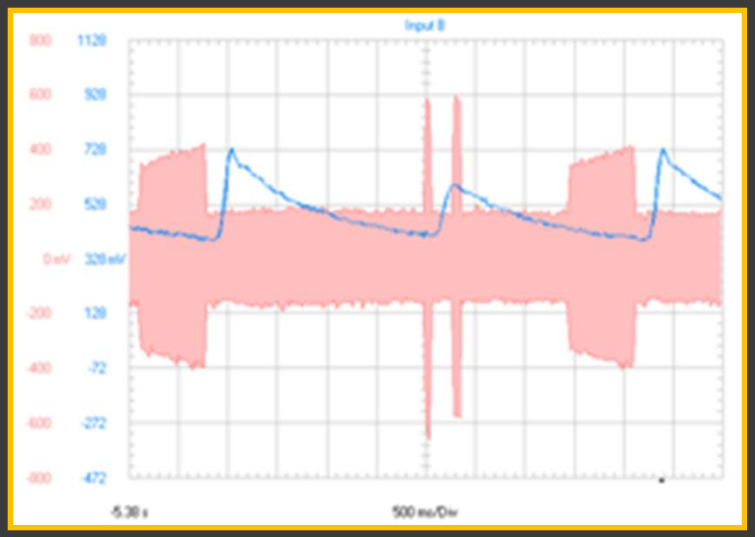




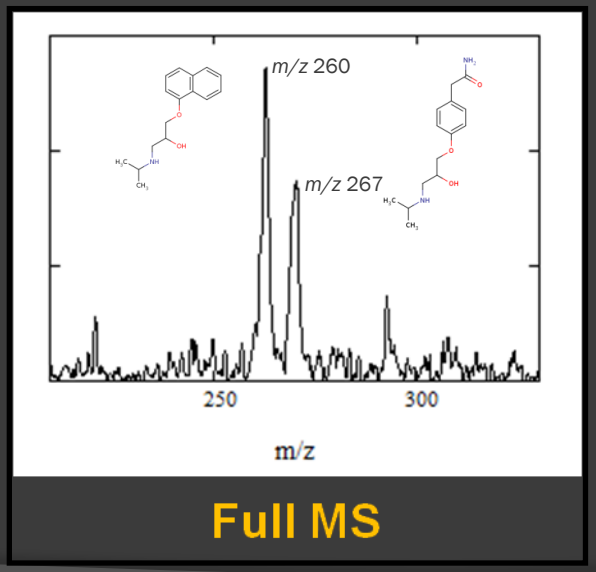




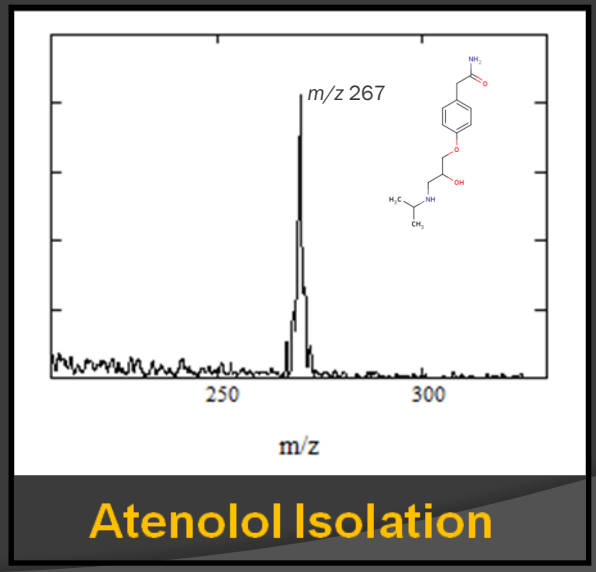
Performance: Tandem MS of atenolol, double DAPI, Full, Isolation, and MS2



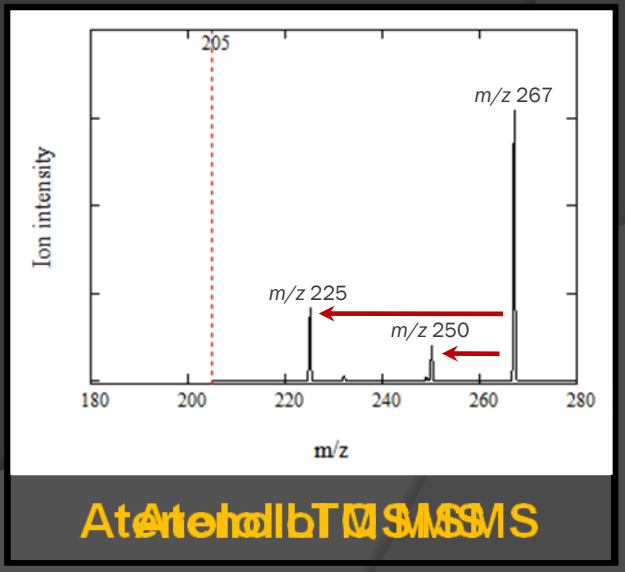
isolation q: 0.434
SWIFT notch: 148.7 to 154.9
isolation time: 75 ms
ion cooling time: 1750 ms
activation q: 0.655
activation time: 30 ms
activation amp: ~1 V_{p-p}
DAPI time: 30 ms
KVDAC: 1.68 Vdc
dDAPI time: 10 ms



Full MS



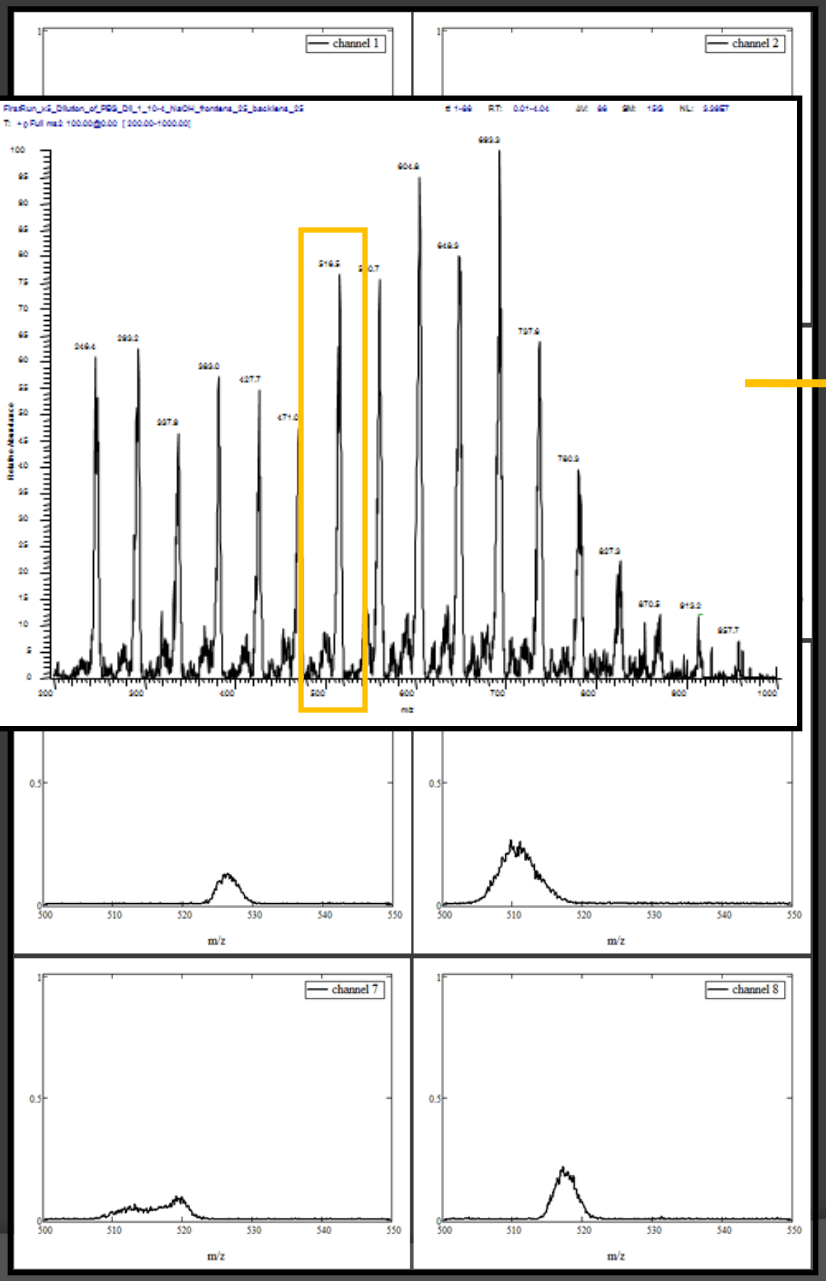
Atenolol Isolation

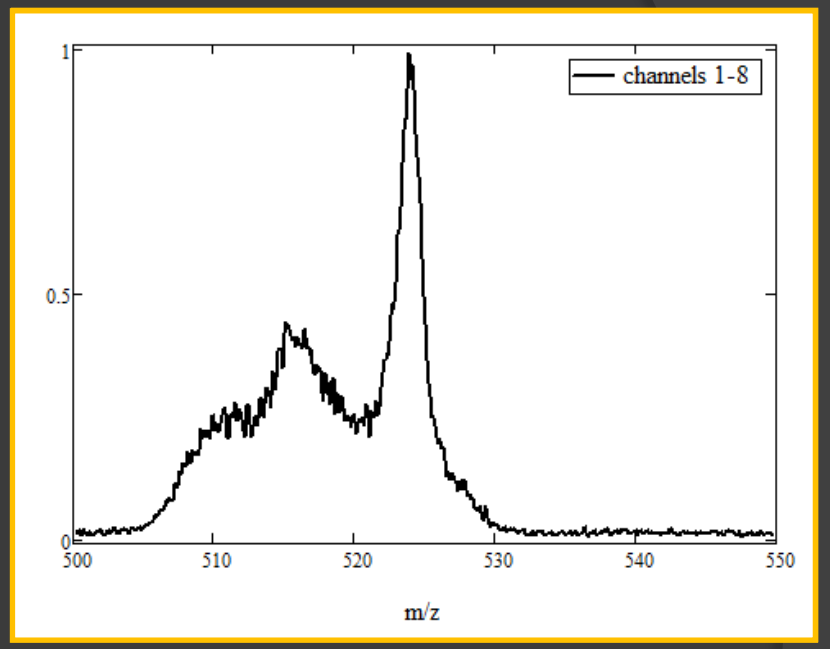


Atenolol TOF MS/MS

L. Gao, G.T. Li, R.G. Cooks, Journal of the American Society for Mass Spectrometry, 21 209-214

Multi-channel data: All eight channels

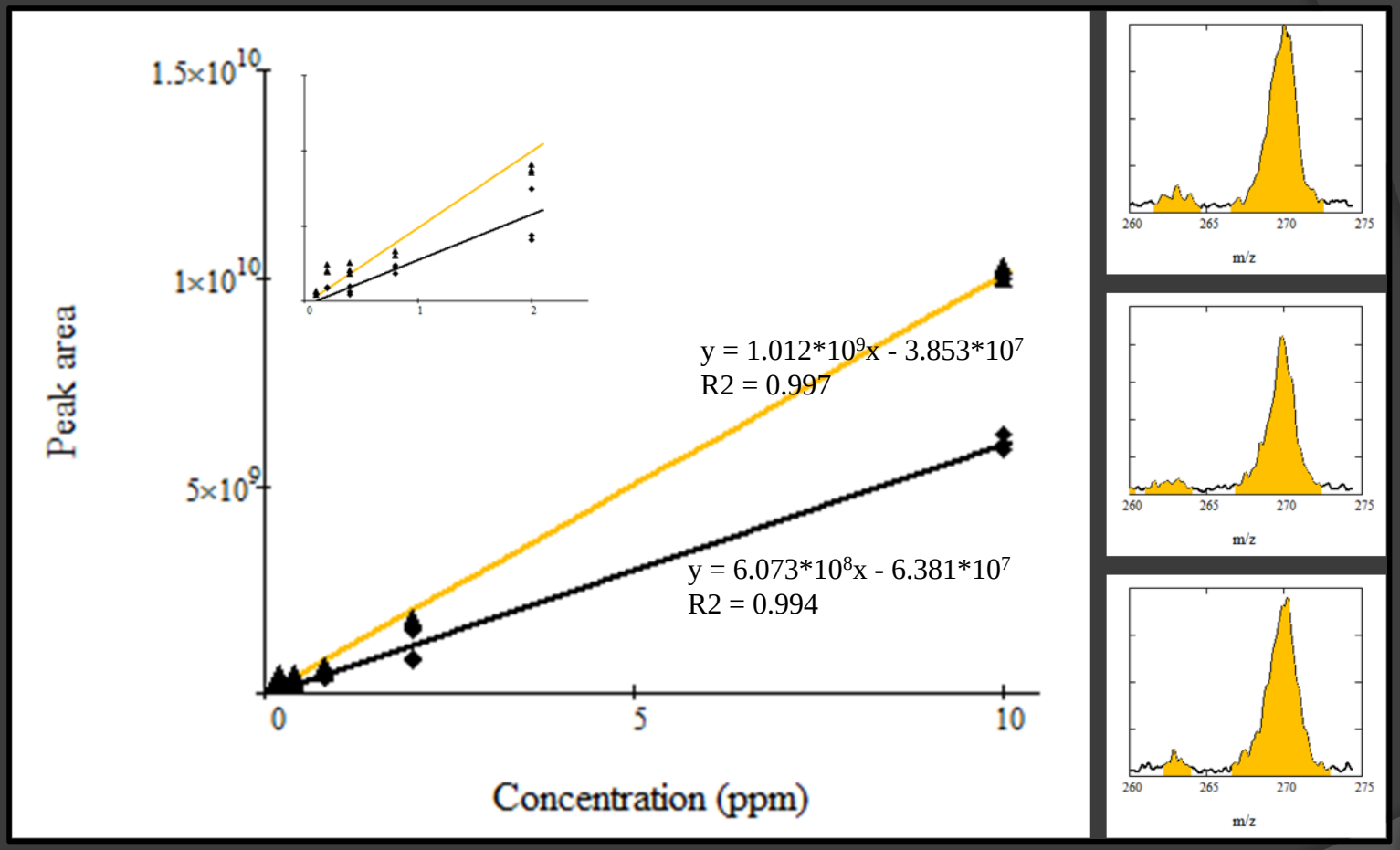




- RF voltages applied to all traps during analysis
- Primary cause of mass shift due Δr_0
- Ejection occurs at a Δ ~5 $V_{0\text{-}p}$ for same m/z
- Δr_0 of ~10s of µm between adjacent traps
- Compensate using individual RF drives

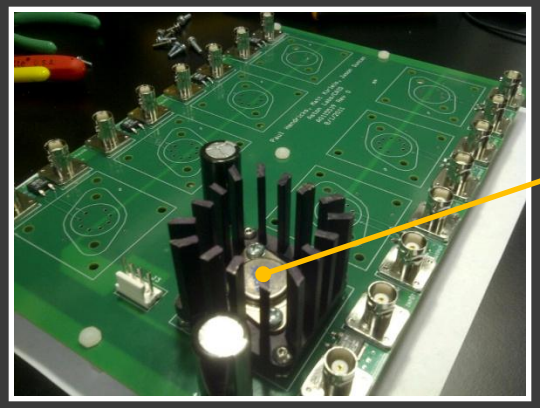
J.D. Mass, P. Hendricks, Z. Ouyang, R.G. Cooks, W.J. Chappell, Journal of Microelectromechanical Systems, 19 (2010) 951-960

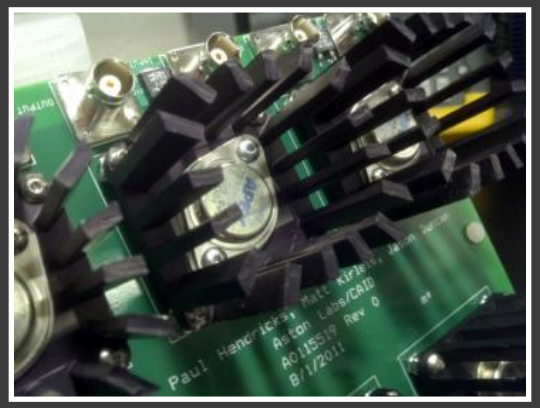
Multi-channel data: Response for multiple vs. single channel



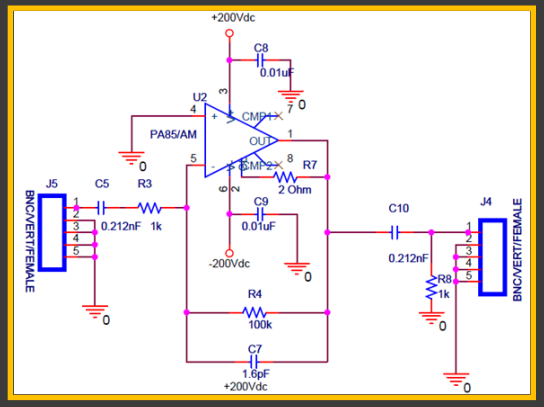
- 0.1 µm/ml to 10 µg/ml dynamic range
- Increased sensitivity & dynamic range with multiple channels
- Development of custom peak detection algorithm
- Peak widths for combined channels 2 – 2.5 amu without RF compensation

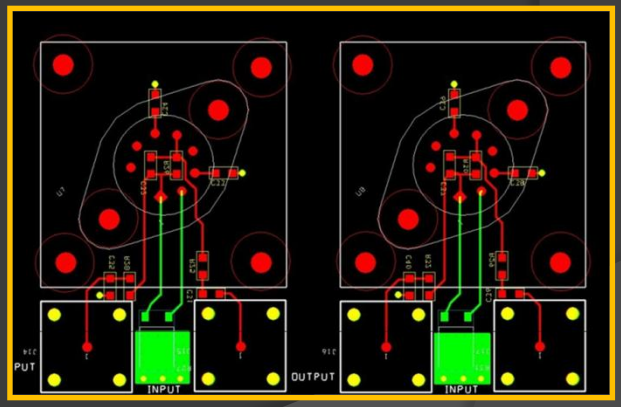
Multi-channel RF drive: High Performance Operational Amplifiers



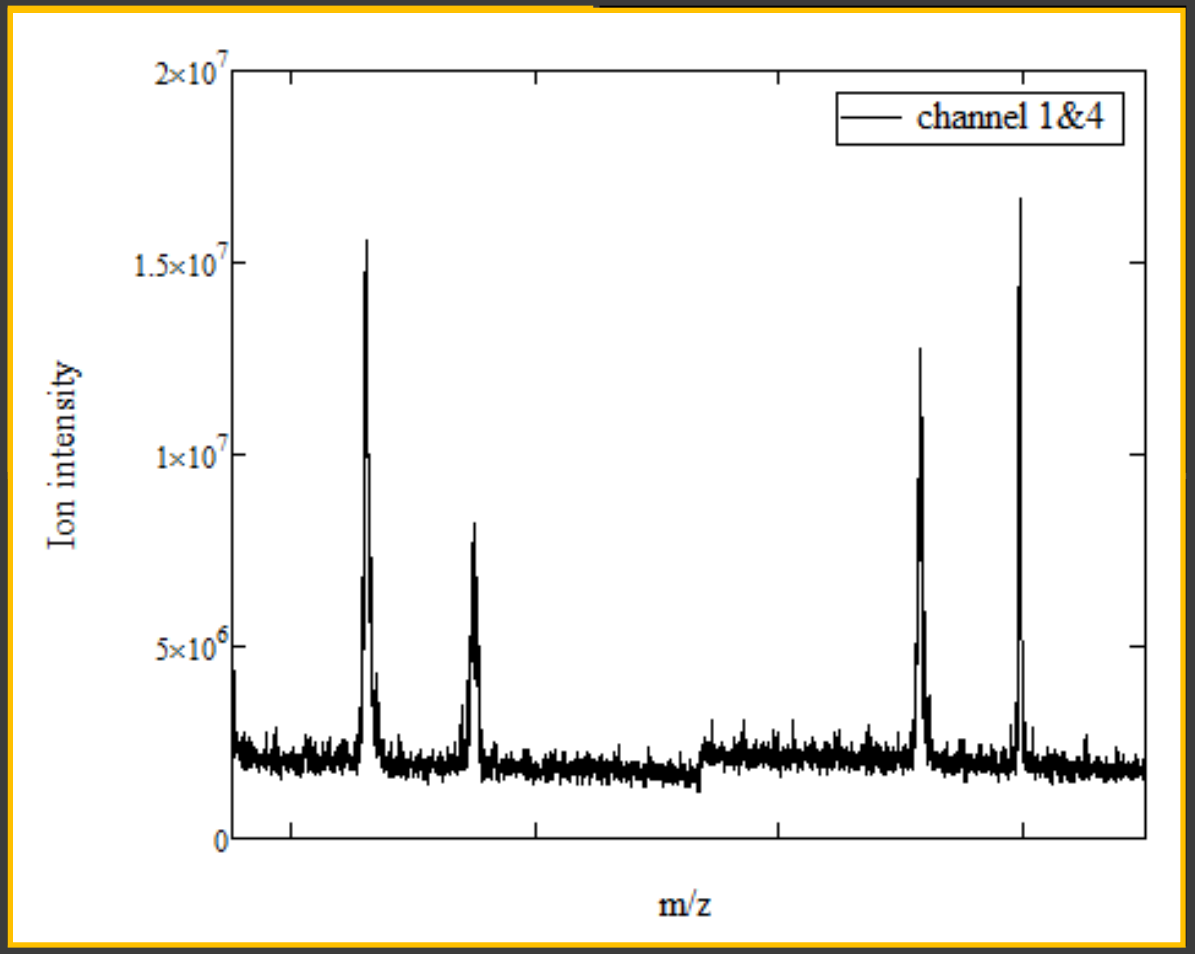


- Independent RF for each ion trap in the array
- Apex PA85 operational amplifier
- 450 V_{p-p} output maximum voltage
- 1000 V/µs slew rate
- Anticipate maximum m/z 500 at 950 kHz
- Cost effective to produce 4 layer PCB

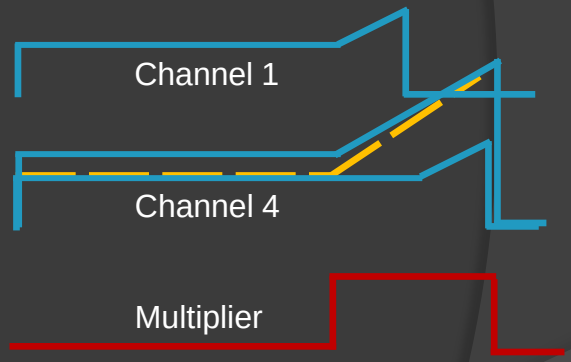




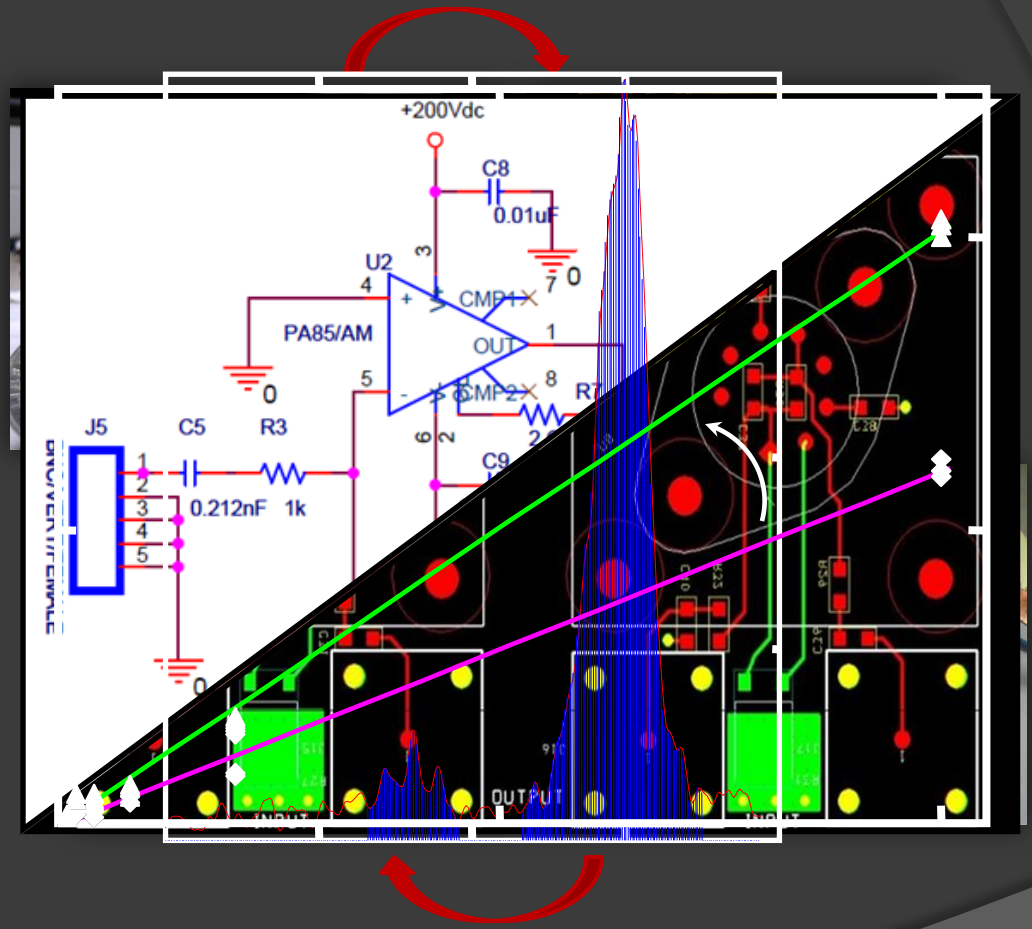
Multi-channel RF drive: Fun with Independent RF Control



- *N*,*N*-Diethyl-3-methylbenzamide
- Lower trapping voltage of channel 1 relative to 4



Combined technology: Ion trap array design, fabrication, and control electronics



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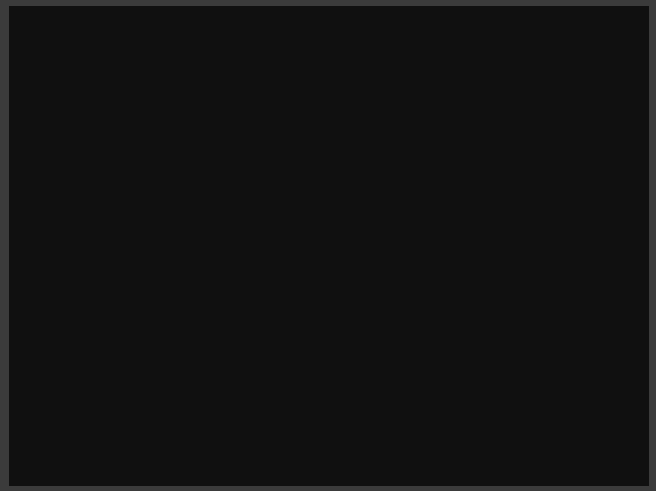
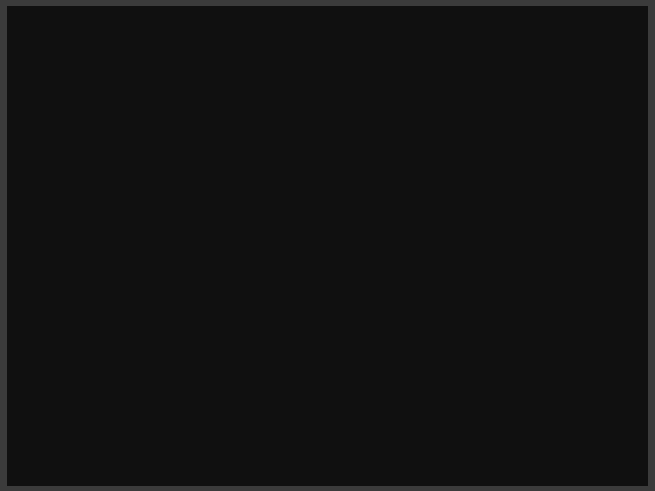
Questions

SLA Fabrication: Build Process and Laser Ablation



Ion Trap Build Process



Laser Ablation: Electrode Isolation