Microfabrication of μ-cylindrical ion trap mass spectrometer arrays

F.H.W. van Amerom[1], A. Chaudhary[2], R.T. Short[2]

[1]University of South Florida,
College of Marine Science
Center for Ocean Technology

[2]SRI International,
Marine Technology Program

Outline

Part I

Mass spectrometry and miniaturization

Part II

Micro CIT-MS and simulations

Part III

MEMS fabrication of micro ion trap arrays

Part IV

Experimental results & Conclusions

Mass spectrometry and miniaturization

Why miniaturize?

Advantages

•Small package for field applications
•Real-time continuous monitoring of chemicals
•Low production costs if using MEMS

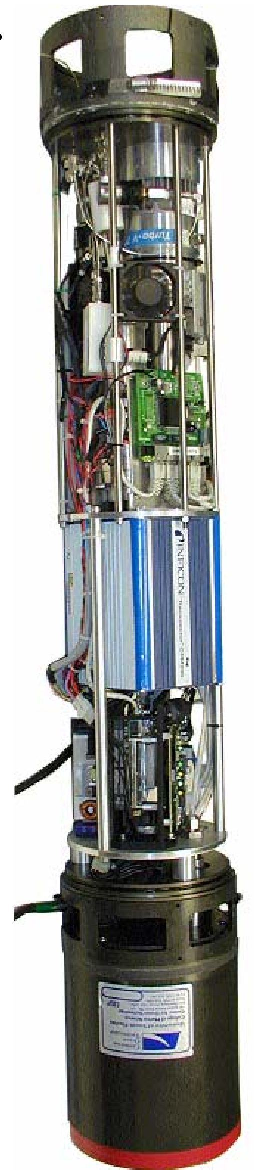
Trade off

•Loss of sensitivity, selectivity
•Often simplistic inlet systems
•Small mass range

We chose to miniaturize quadrupole ion traps

•Operates at moderate vacuum
•Capable of MS^n
•Sensitivity excellent

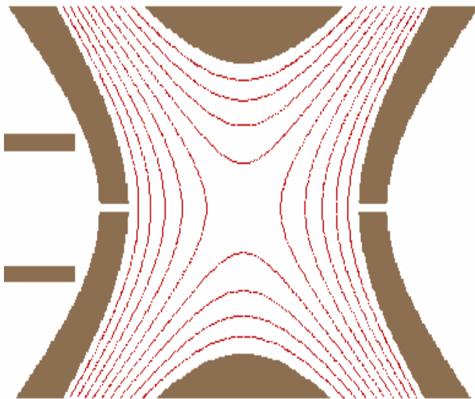
1.25 m

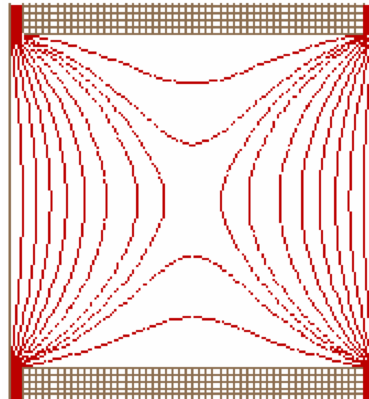


Quadrupole ion trap v.s. cylindrical ion trap

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

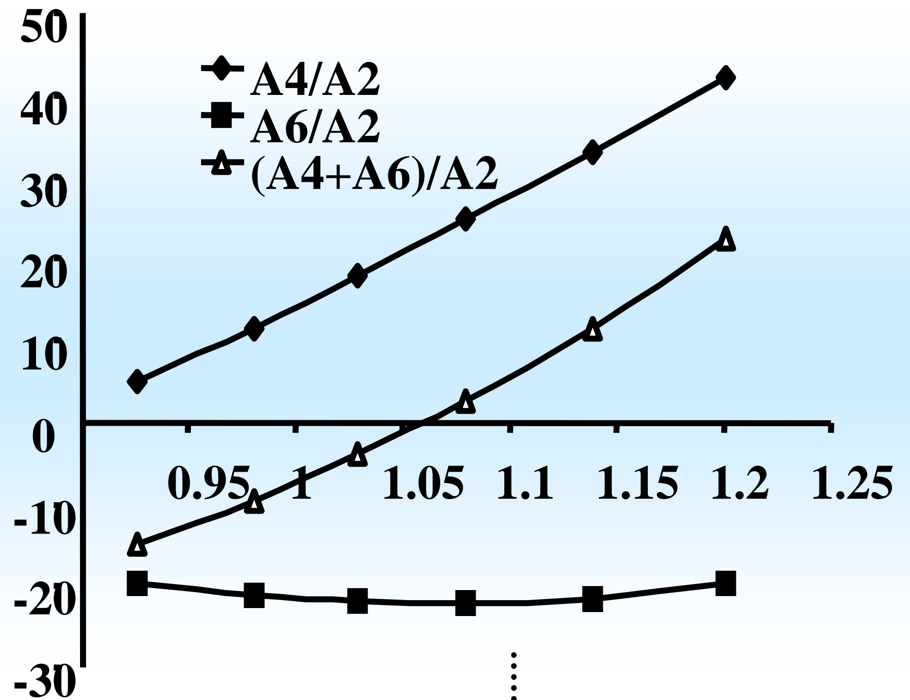
- Cylindrical structure easy to machine while quite similar electric potential
- Lower power but electric potential well depth reduced



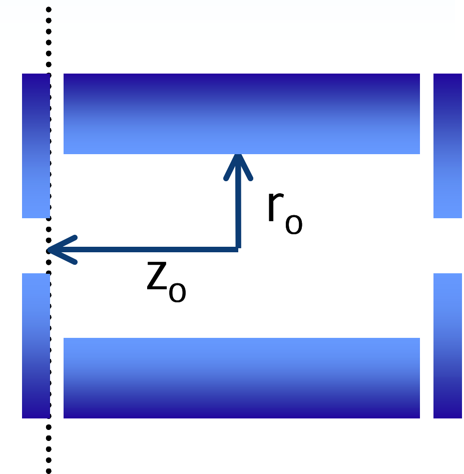


Quadrupole ion trap v.s. Cylindrical ion trap

$$A_2^{\mathrm{R}} \approx 1$$



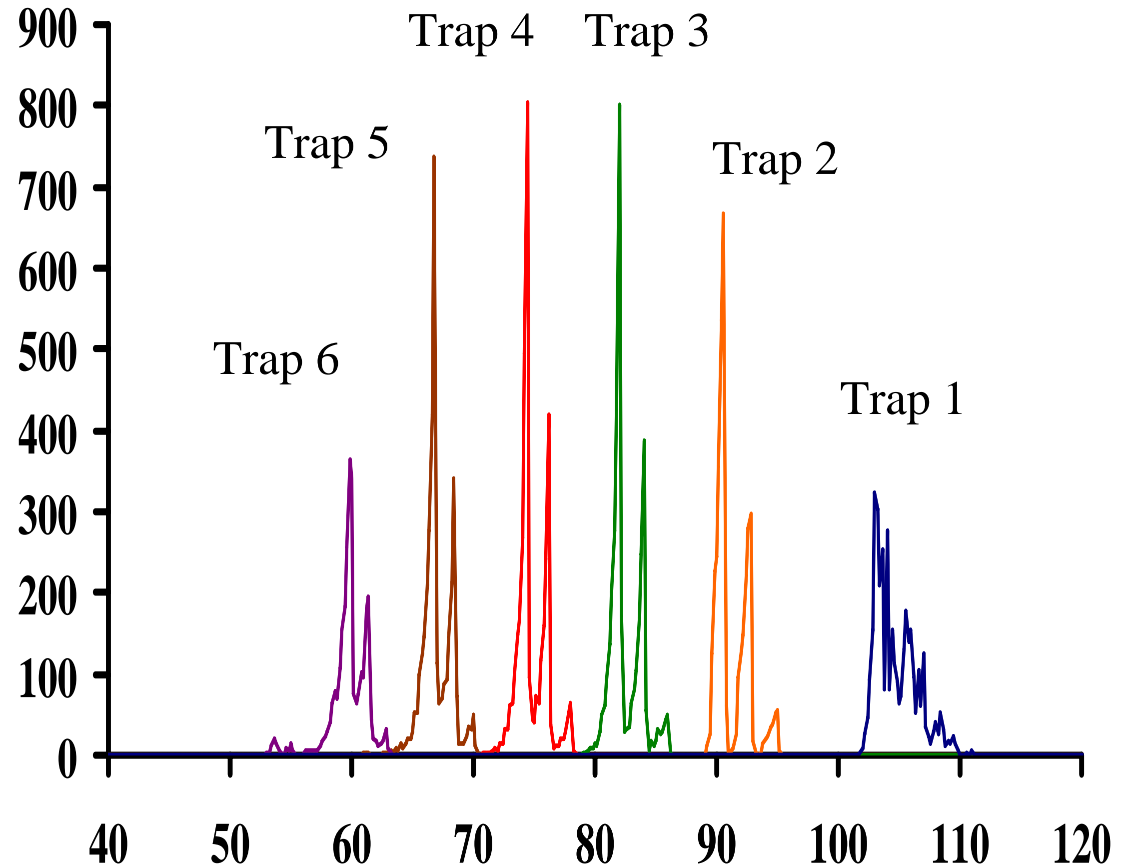
$$A_{2n}^{\mathrm{R}} \approx -\frac{2}{(2n)!} \cdot \sum_{i=1}^{\infty} \frac{x_i^{2n-1}}{\cosh\left(\frac{z_0}{r_0} x_i\right) \mathrm{J}_1(x_i)} + \delta_{n,0}$$



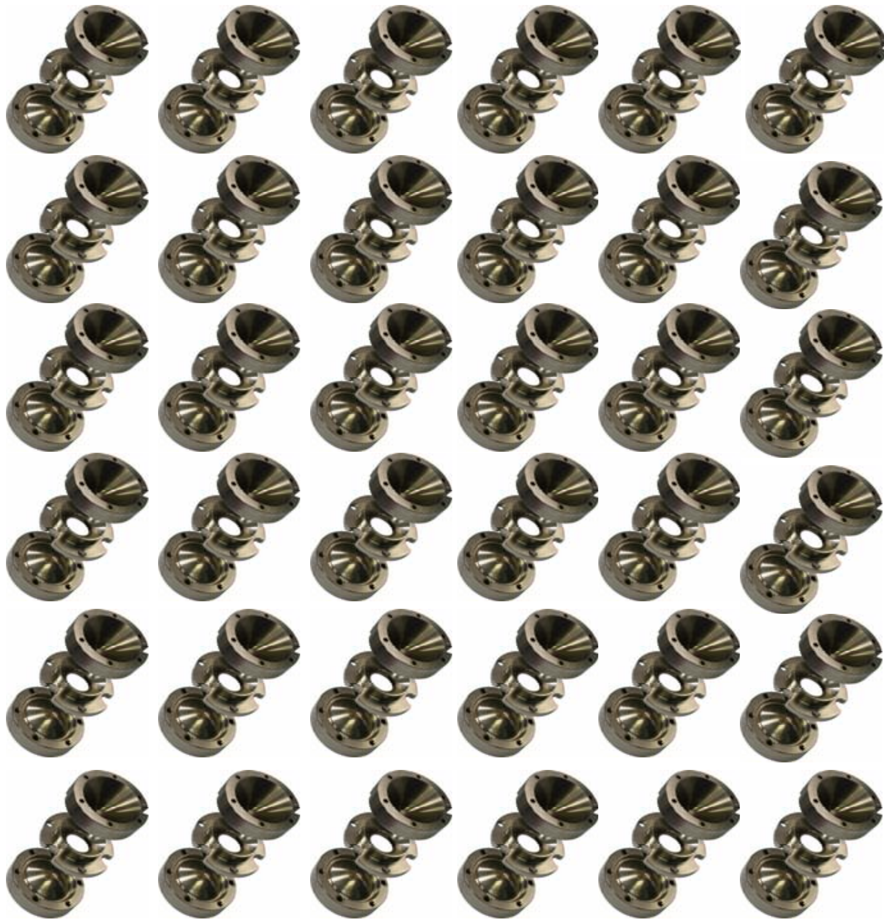
Simulations to optimize CIT geometry

$z_0 = 350\ \mu m$

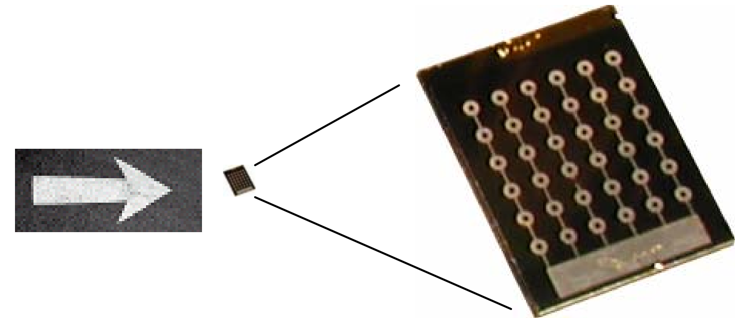
Trap #	z_0/r_0	r_0 µm
1	0.92	381
2	0.97	360
3	1.02	343
4	1.07	327
5	1.13	310
6	1.19	294



MEMS fabrication of CIT array

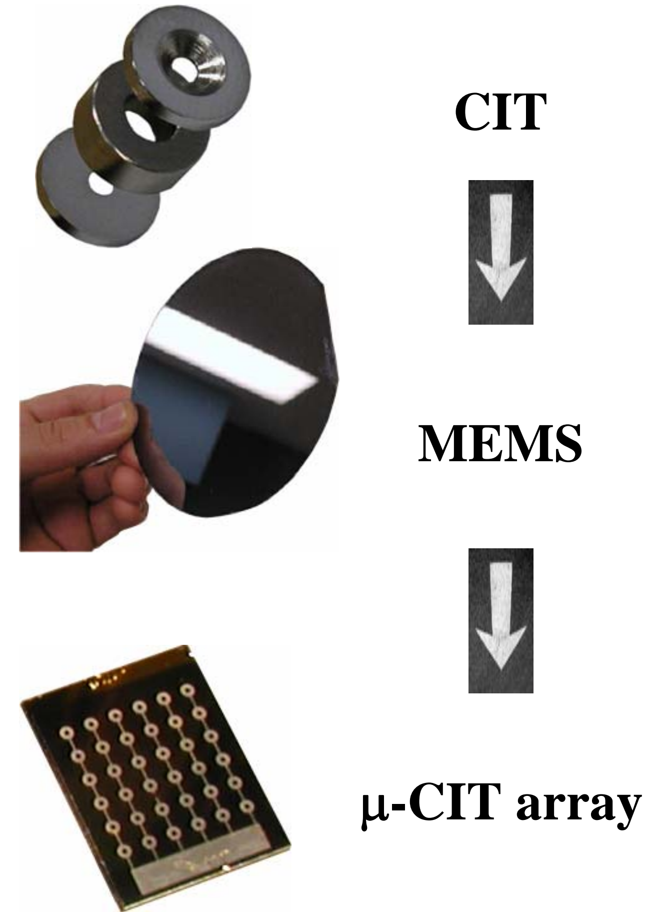


•High resolution, sensitivity, mass range, power consumption



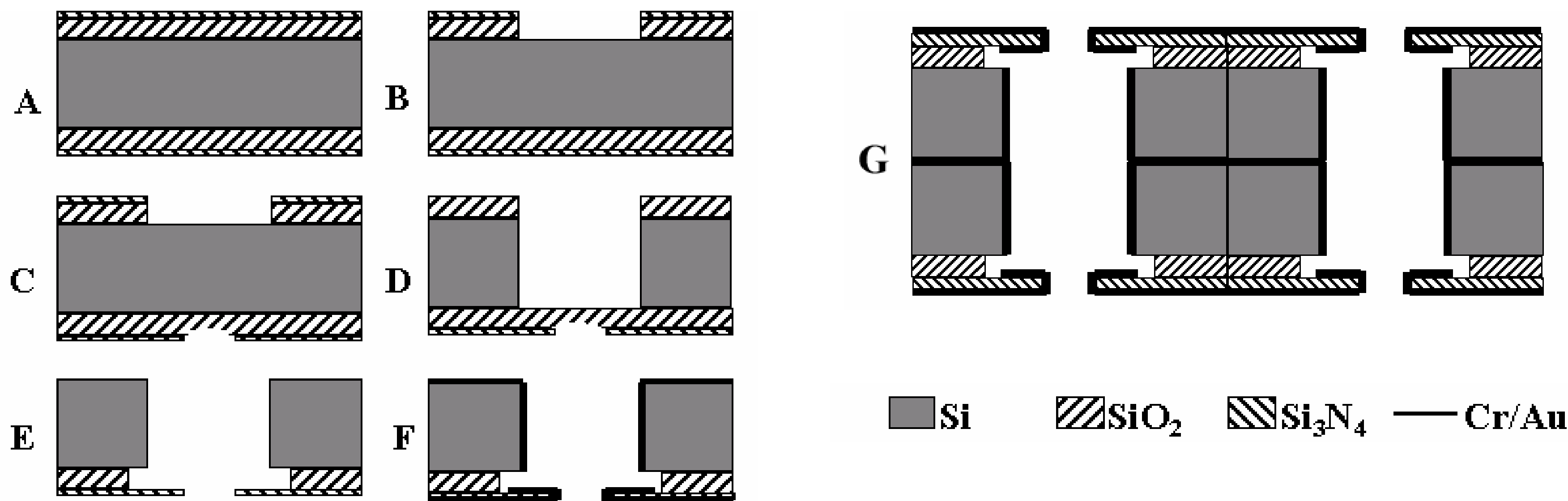
•Low voltages, portable, parallel analysis, operation at moderate vacuum,
•Arrays should lead to increased sensitivity

MEMS fabrication of CIT array



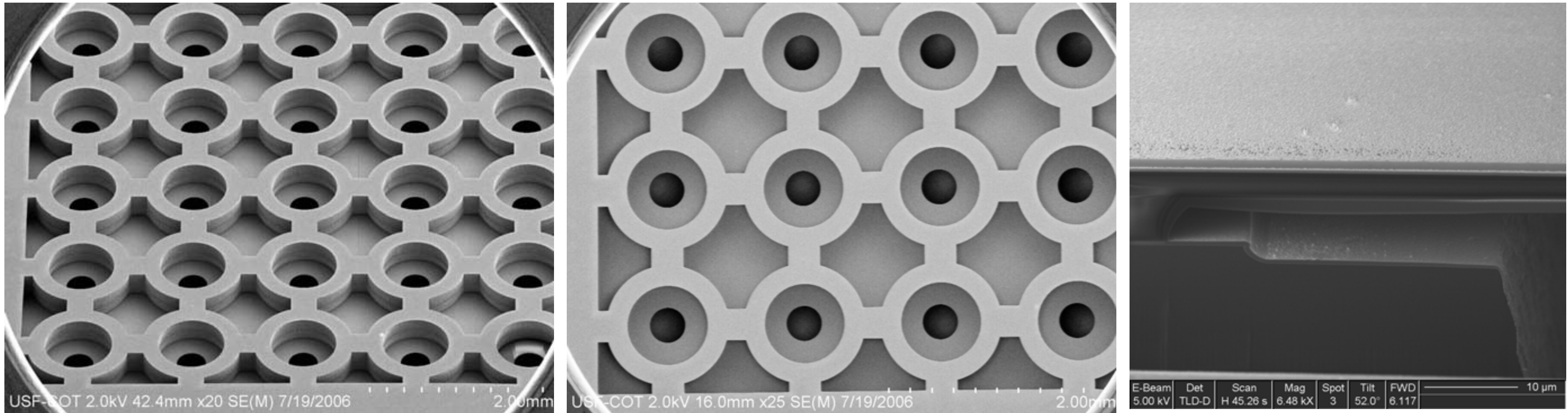
Capabilities of MEMS facility: PECVD, RIE, DRIE, e-beam evaporator, 4 tube LPCVD and 2 sputtering systems, JEOL SEM, the Hitachi high resolution SEM and the FEI dual beam FIB.

Process flow



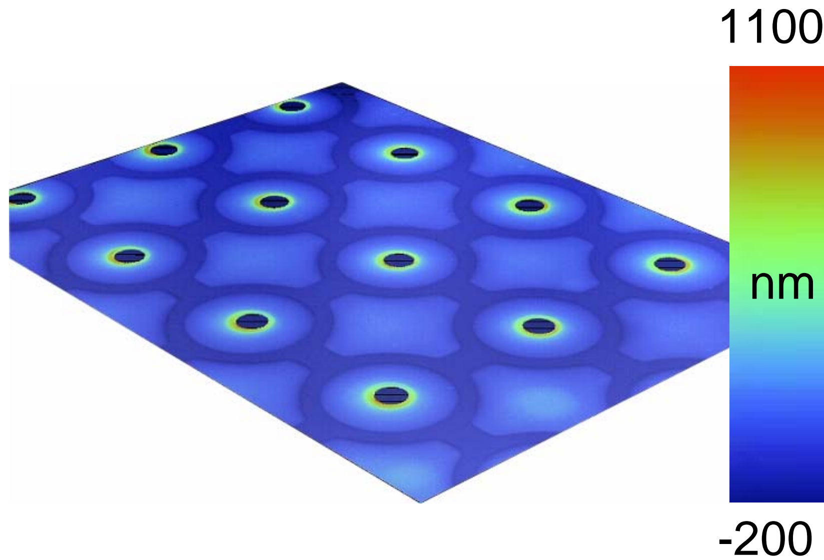
A) SiO_2 grown, LPCVD Si_3N_4 deposited on Si.
B) Si_3N_4 and SiO_2 patterned.
C) Si_3N_4 patterned and etched on the backside: SiO_2 was partially etched in BOE.
D) Si etched using DRIE.
E) Residual SiO_2 etched in HF 49%.
F) Cr/Au layer sputtered onto both sides to obtain a conductive half μ-CIT structure.
G) Two half structures bonded back to back.

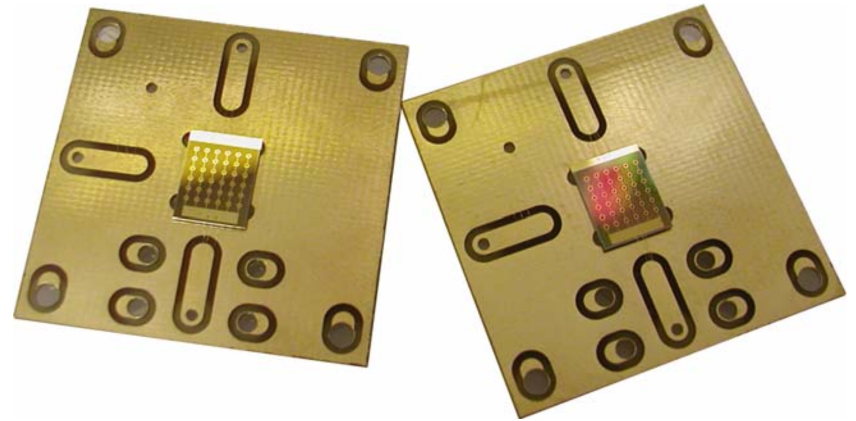
Results: MEMS fabrication



- Three design iterations
- DRIE parameters were optimized for radius 360 µm to obtain a cylinder wall verticality of better than 89 °
- Different sizes could be fabricated with minor process adjustments
- Capacitance reduced to 215 pf

Results: MEMS fabrication





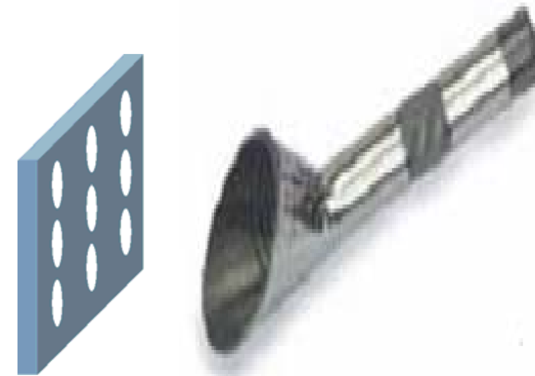
•3-D profile of the Si_3N_4 membranes showing outward bow.

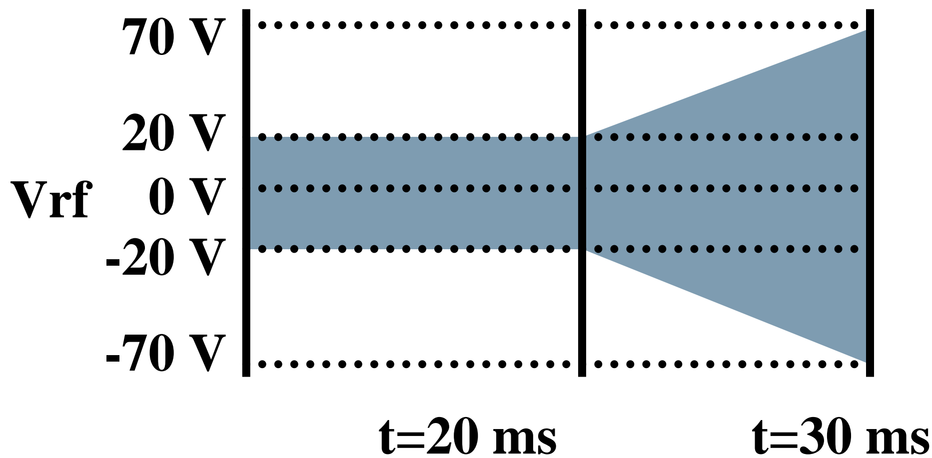
•μ-CIT arrays were mounted on a customized Au plated PCB for testing.

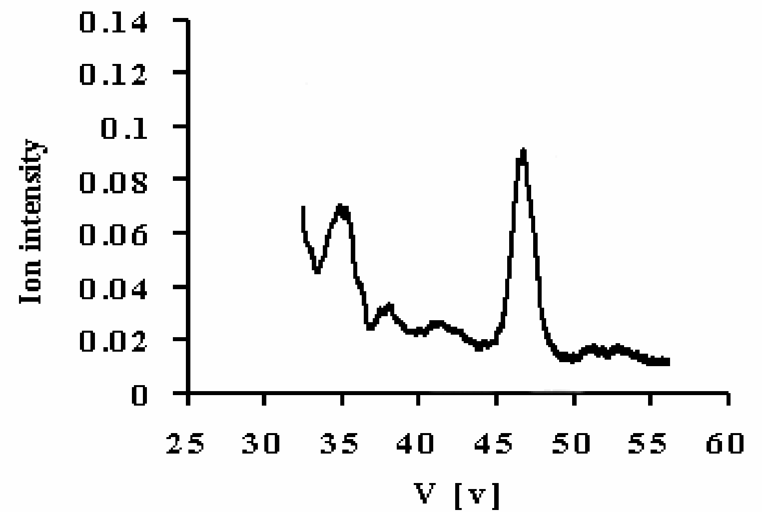
Experimental setup

electron gun

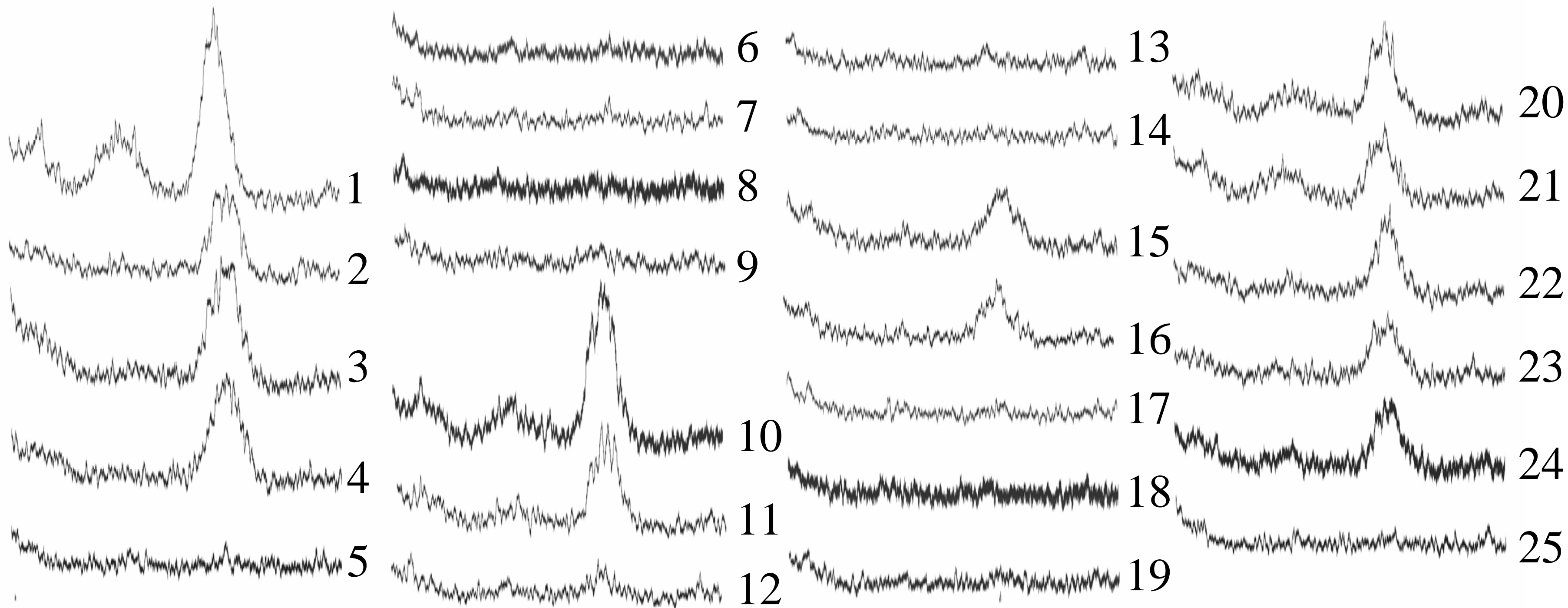
μ-CIT array detector







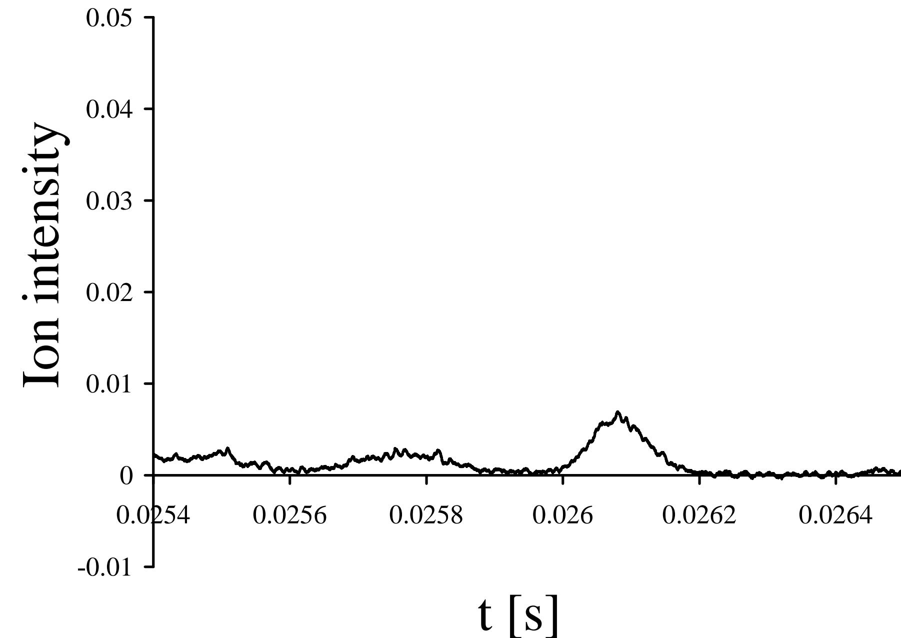
Results: Characterization of μ-CIT array

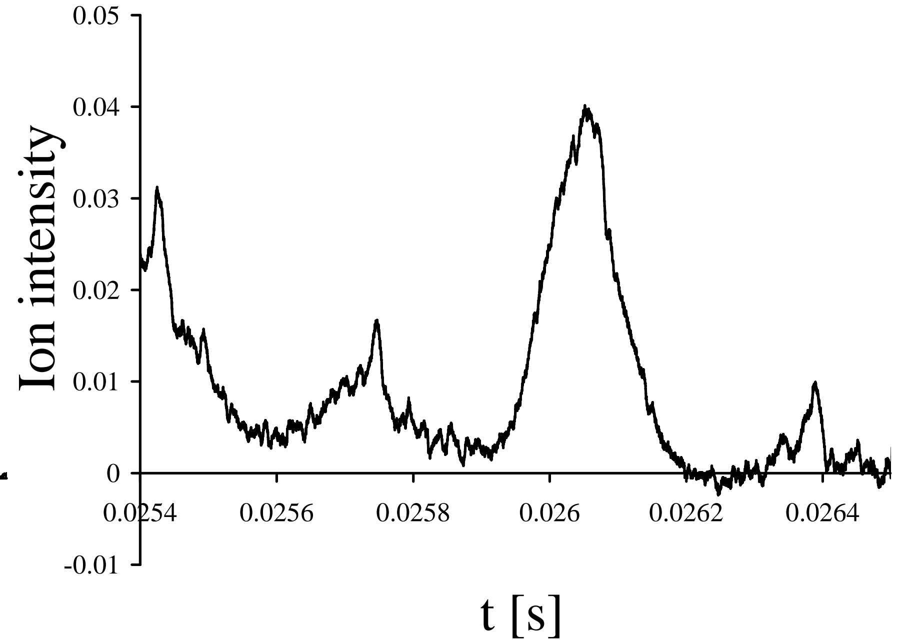


•PFTBA spectra (buffer gas helium) from each individual CIT

Results: Characterization of μ-CIT array

Detech electron multiplier

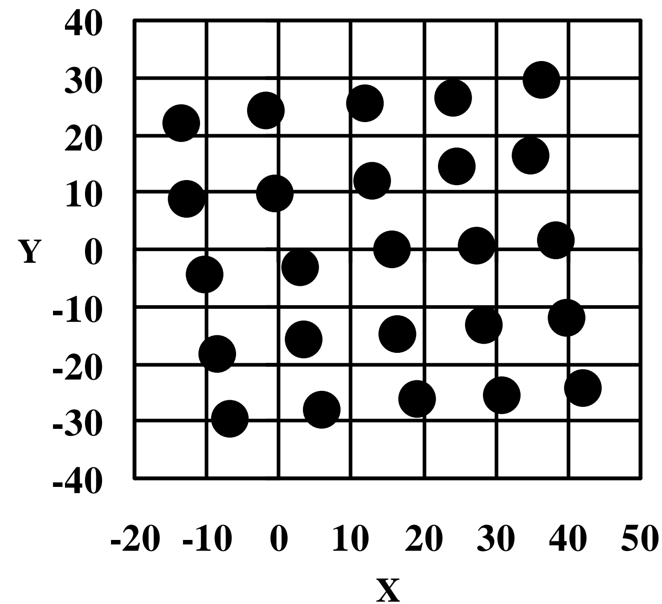




- Sum of all spectra shows increase in intensity

Results: Characterization of μ-CIT array

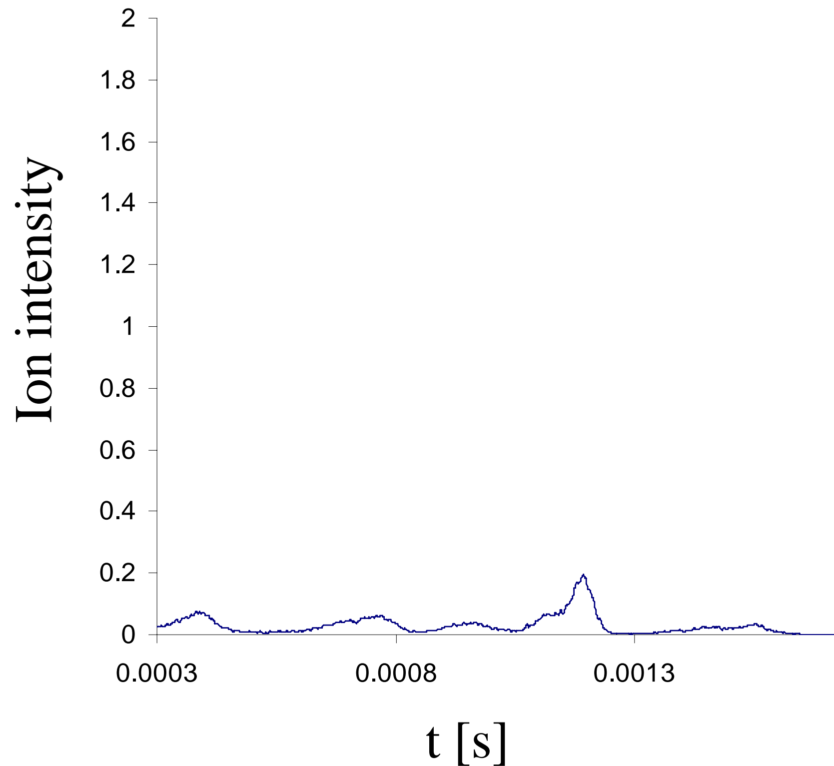
Detech electron multiplier

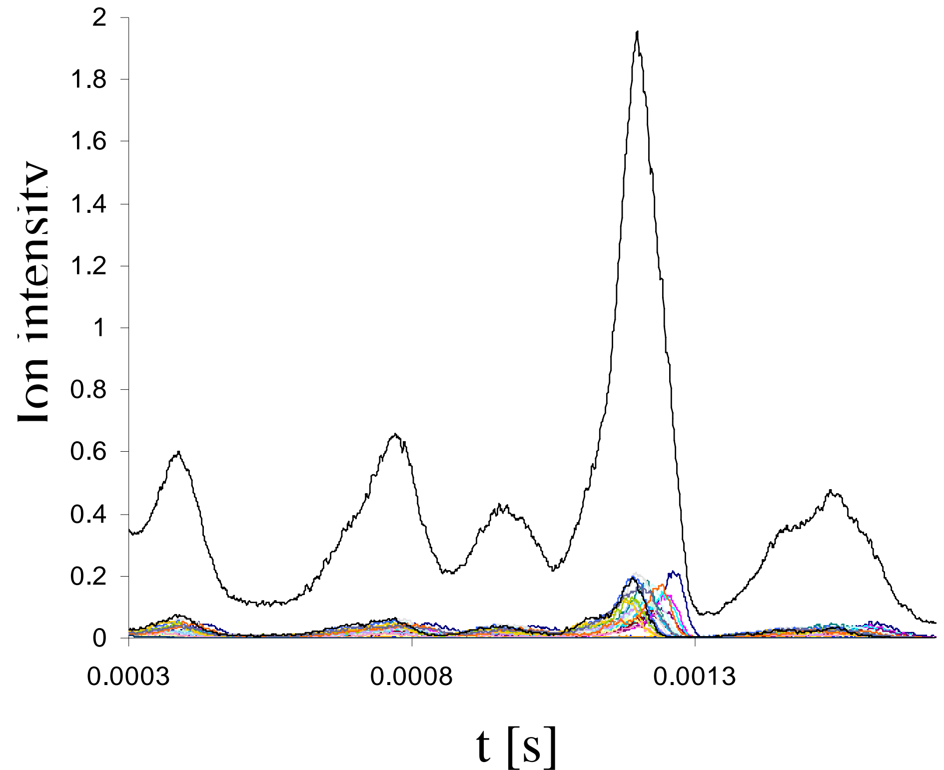


PFTBA

•Spatial representation of peak height

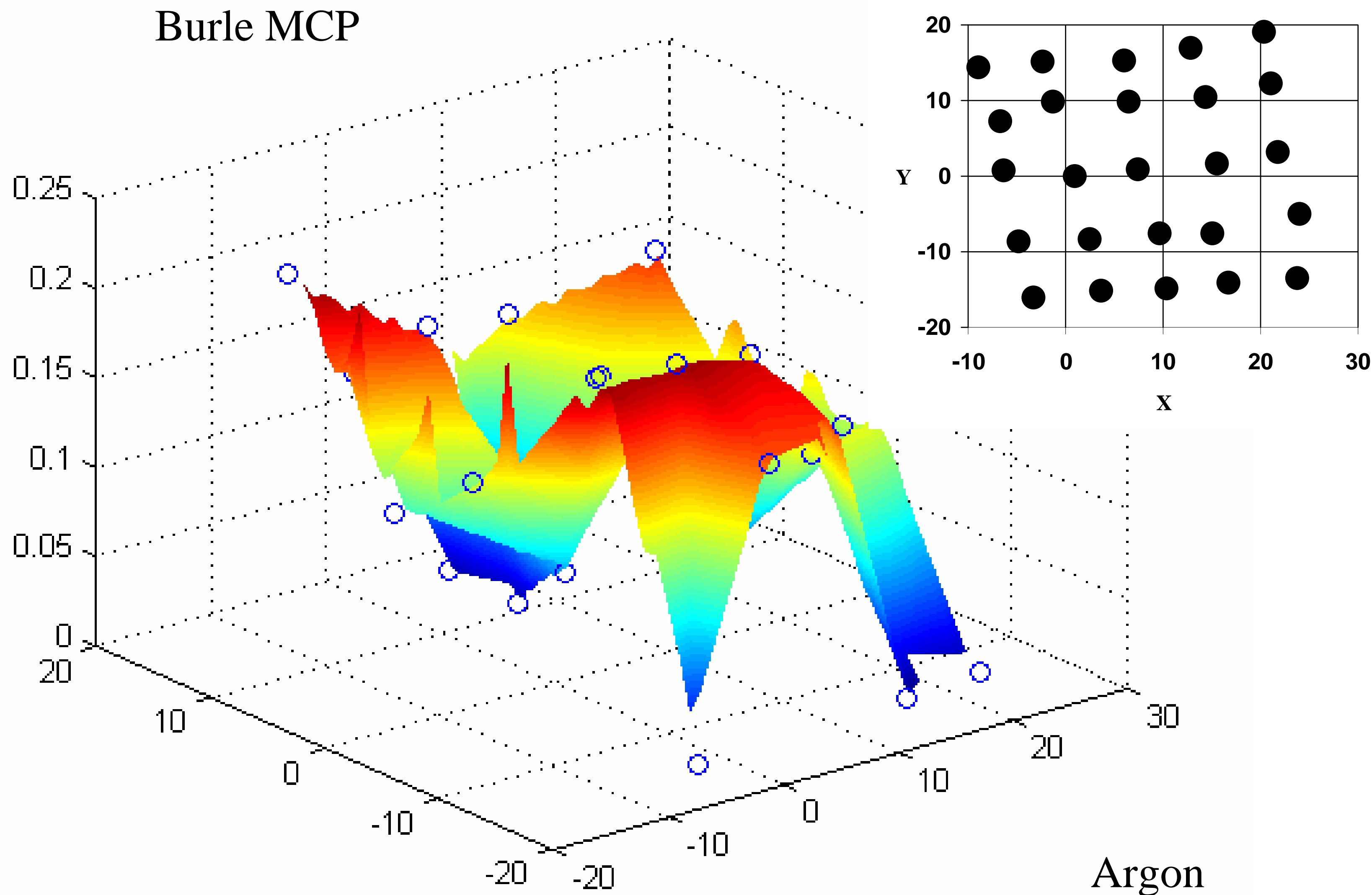
Results: Characterization of μ-CIT array





- Sum of all Argon spectra shows increase in intensity

Results: Characterization of μ-CIT array



Future

MEMS fabrication techniques

GC column

Pump

Inlet system

Mass spectrometer
Ion optics

Ionization source

Detector

Integration into small package

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