MICRO-ION TRAPS FOR DETECTION OF (PRE-) BIOTIC ORGANIC COMPOUNDS ON COMETS

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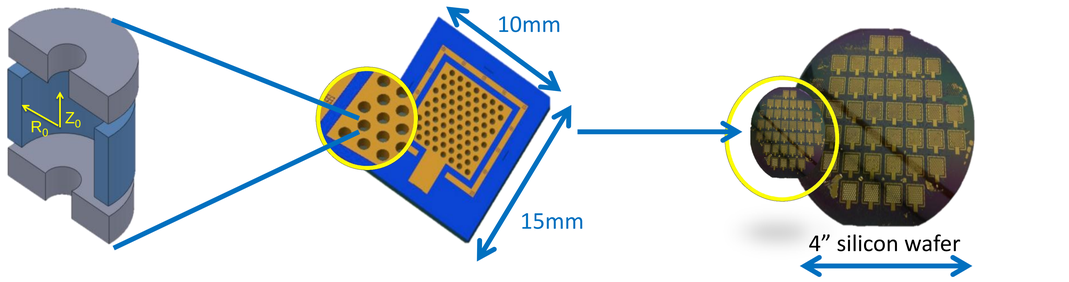
INTRODUCTION

Comets are currently believed to be a mixture of interstellar and nebular material. Many of the volatiles in comets are attributed to interstellar chemistry, because the same species of carbonaceous compounds are also observed in ices in interstellar molecular (ISM) clouds. Comets are thus likely to be relatively pristine reservoirs of primitive material and carbonaceous compounds in our solar system. They could be a major contributor to the delivery of prebiotic organic compounds, from which life emerged through impacts on early Earth. Mass spectrometers are very powerful tools to identify unknown chemicals, and much progress has been made in miniaturizing mass spectrometers for space applications. Most miniaturized mass spectrometers developed to date, however, are still relatively large, power-hungry, complicated to assemble, and would have significant impact on space flight vehicle total payload and resource allocations. Proof-of-concept high-precision arrays of extremely small (ca. 350 µm *r0*) µ-cylindrical ion trap geometries (µ-CITs) in silicon, and silicon-on-insulator substrates using microelectromechanical systems (MEMS) were fabricated. µ-MSs could be important for guiding sample return missions to targets by helping to identify optimal locations to collect samples, and will be valuable for analysis of volatile compounds released from samples immediately after collection or during transit back to Earth.

MICROFABRICATION of HD µ-CIT ARRAY

- Concept of CIT miniaturization



a. Cross-sectional view of a single macro-scale CIT machined in metal.

b. Miniaturize the dimension of each CIT to micro-scale, and pack them into a high-density array. To clearly illustrate the concept, only ring electrode chip design is shown.

c. Microfabrication processes are used to batch fabricate multiple HD µ-CIT arrays on a single 4" Si wafer.

- CIT Design Optimization and Microfabrication Process

Ring Electrode

❖ **High-density array**
- Hexagonal orientation of CITs in an array allows higher trap density.
- About 70-80 CITs can be packed into a single chip (1 x 1.5 cm).
- Cylinder holes are etched in Si by deep reactive ion etching (DRIE) in Si.

❖ **Improved signal intensity**
- Higher density array allows higher ion storage capability.
- Signal intensity should be more than twice that previously achieved.

❖ **Conducting layer patterning**
- Chrome and gold are deposited on both surfaces and on the sidewall of the cylinder holes as the conducting layer.
- Cr/Au layers are selectively patterned to reduce the device capacitance.

Endplate Electrode

❖ **Suspended endplate electrode structure**
- The contact area of ring electrode and endplate electrode was reduced from 15 mm^2 to 3 mm^2 to reduce the device capacitance.
- A gap of 60 µm was incorporated between endplate electrodes and ring electrode to further reduce the capacitance.

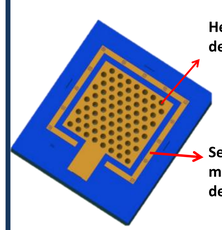
❖ **Device capacitance can be further reduced**
- By calculation, the new design will give a capacitance of 59 pF.

❖ **Higher scanning voltage can be applied and broader mass range can be obtained**
- The real mass range measurement is in progress now.

Multi-anode Detector

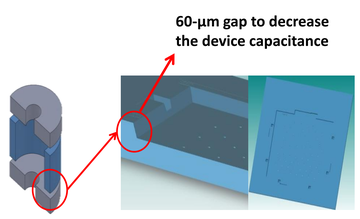
❖ **A hexagonal high-density array of circular detectors**
- Multiple anodes to be able to measure mass spectra from each individual CIT in the array separately.
- Anodes of several dimensions have been incorporated in the mask to investigate trap performance .
- Process developed to fabricate the multi-anode detector in Si wafer.

❖ **The Multi-anode detector was mounted on a custom-designed printed circuit board (PCB) to lead the signal from each trap to an external oscilloscope for mass spectra.**

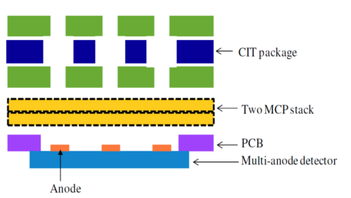


Hexagonal oriented high-density CIT array

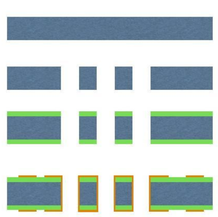
Selectively patterned metal layer to reduce device capacitance



60-µm gap to decrease the device capacitance



Multi-anode detector setup

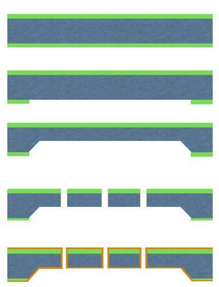


Starting with a 4" diameter, 530-µm thick Si wafer

DRIE etch all the way through to create the HD cylindrical holes.

Double side SiO_2 deposition using plasma-enhanced chemical vapor deposition.

Sputtering of Cr/Au on both sides of the Si wafer. Sidewall is also coating effectively during sputtering. Then lift-off is performed to pattern the metal layer.



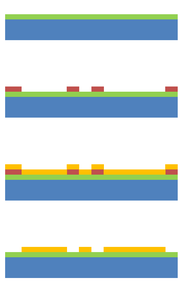
Starting with a 4" diameter, 370-µm thick Si wafer, with 2 µm SiO_2 on both sides.

Pattern SiO_2 on one side. The remaining SiO_2 will be used as hard-mask for next step.

Potassium hydroxide (KOH) was used to etch Si to form the 60-µm gap.

DRIE to obtain through-holes from the other side of the wafer.

Sputtering of Cr/Au on both sides of the wafer.

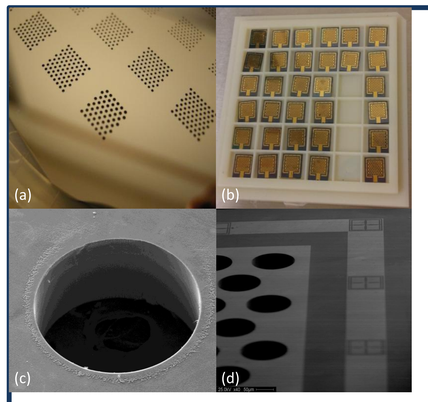


Starting with a 4" diameter wafer, with 2-µm SiO_2 on the surface as insulating layer.

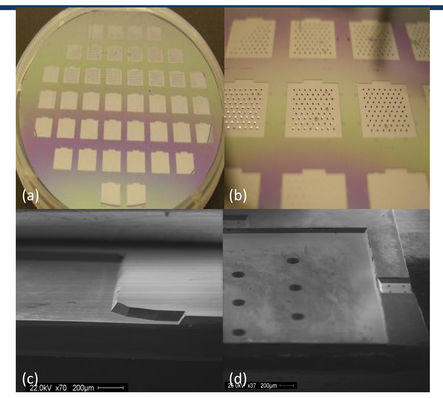
3000PY photoresist photo-lithography.

Cr/Au was deposited by e-beam evaporation on the insulating layer.

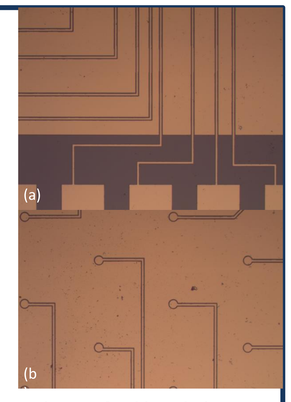
Metal lift-off was performed to pattern the metal layer and form the anode array.



Images of microfabricated ring electrode
(a) Ring electrode cylindrical through-holes on Si wafer after DRIE.
(b) Ring electrode chips with metal pattern after dicing.
(c) SEM image of a cylindrical hole before metal deposition.
(d) SEM image of the corner of the ring electrode chip showing the metal pattern for the bonding pad, with alignment marks.



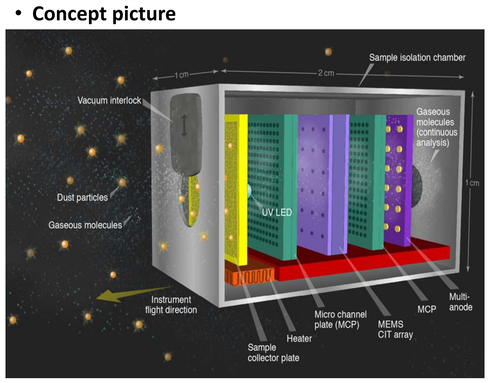
Images of microfabricated endplate electrode
(a) Endplate electrode fabricated in Si with a recessed cavity to obtain a 60-µm gap between the ring and endplate apertures.
(b) Image of the endplate chips showing the DRIE etched aperture in the KOH etched cavity.
(c) SEM image of the recessed cavity in endplate substrate for capacitance reduction.
(d) SEM image of the endplate electrode, showing the DRIE etched endplate aperture in the cavity.



Microscope images of multi-anode detector array
(a) Conductive strips are used to carry the ion signal impinging on each anode aligned with the corresponding CIT in the array. The surrounding metal acts as a ground plane and is used to prevent charge accumulation.
(b) Each anode and its conductive metal strip is insulated from the ground plane by a 5-µm lateral gap.

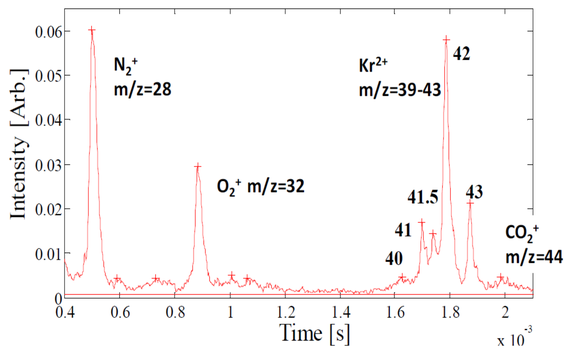
CONCEPT

- **Concept picture**



Vacuum chamber accepting particles and molecules from the comet's jets.

- **Preliminary measured results from micro mass spectrometer**



A spectrum of Krypton2+ and background earth atmosphere

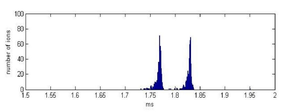
CHEMISTRY & SIMULATION OPTIMIZATION

Table 1: Overview of Chemical Compound Concentrations in Meteorites, Comets, and Interstellar Clouds, and Measurement Goals for the µ-CIT Array MS

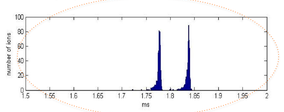
Chemical compounds to be measured	Molecular ion *m/z*	Minimum sensitivity for µ-CIT array	Observed concentration	Meteorite	Reference
Methane	16	<500 ppb	unknown		
Methylamine	31	<500 ppb	unknown		
Ethylamine	45	<500 ppb	unknown		
Formaldehyde	30	<500 ppb	unknown		
Glycine	75	<500 ppb	750 ppb	Stardust aerogel	[14]
			10 pmol/cm^3	Stardust foil	[11, 16]
			707±80 ppb	Orgueil	[12]
			617±83 ppb	Ivuna	[12]
			2919±433 ppb	Murchison	[12]
			2110±144	Murray	[12]
DL-Isovaline	117	<500 ppb	2400 ppb	Murchison	[13]
			23000-29000 ppb	EET 92042, GRA 95229	[13]
β-Alanine	89	<100 ppb	2052±311 ppb	Orgueil	[12]
			1401±146 ppb	Ivuna	[12]
			1063±268 ppb	Murray	[12]
			1269±202 ppb	Murchison	[12]
L-Lysine	146	<500 ppb	unknown		
L-Tryptophan	204	<500 ppb	unknown		
Glycolaldehyde (sugar aldehyde)	60	<500 ppb	unknown		
Ethylene glycol (sugar alcohol)	62	<500 ppb	unknown		
Pentanal	86	<500 ppb	unknown		
2-Decanone	156	<500 ppb	unknown		

❖ Chemical compounds reported in literature found in meteorites and comet dust. These compounds are important precursors of life.

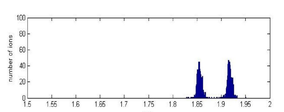
Z_0/R_0=1.09



Z_0/R_0=1.00



Z_0/R_0=0.9



❖ A series of simulations to investigate the performance of ion traps with various geometries. z_0 ranges from 270 to 325 µm, and r_0 varies from 250 to 350 µm. Optimized mass resolution is at z_0/r_0 approaches 0.97, which is consistent with previous work.

REFERENCES & ACKNOWLEDGEMENTS

Ashish Chaudhary, Friso H. W. van Amerom, and R. Timothy Short, "Development of Microfabricated Cylindrical Ion Trap Mass Spectrometer Arrays", *Journal of Microelectromechanical Systems*, Vol. 18, No. 2, April 2009. Acknowledgement to Tianpeng Wu and Jing Wang for preliminary work under NSF funding. Funding received from the U.S. Army Space and Missile Defense Command (SMDC) through contract W9113M-06-C-0022 with USF (Subcontract to SRI International). Distribution A: Approved for public release; distribution unlimited. The views and conclusions contained in this presentation are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the Government. This material is based upon work supported by the National Science Foundation under Award No. 0923977. Any opinions, findings, and conclusion or recommendation expressed in the publication are those of the authors and do not necessarily reflect the views of the National Science Foundation . ASTID funding award #NNX12AQ26G.