SAND2007-2246P

Microsensors and Micro-Analytical Systems For National Security Applications

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Sandia National Laboratories
Albuquerque, NM 87185

Abstract

Sandia National Laboratories has a long tradition of technology development for national security applications. Among the resources that drive these critical developments are world-class microfabrication facilities capable of product-quality components *and* diverse, cutting-edge research. In recent years, we have utilized this vast micro-technology resource to investigate integrated microsensors and complex micro-analytical systems, i.e., miniature and portable tools built around microfabricated components that have the functionality of bench-scale instruments. One area of high interest to many national security customers is the development of systems/instruments that target detection and analysis of chemical and biological agents. As we look to the future, the ultimate goal for these analytical instrument developments is to produce fully integrated sensored microsystems.

This presentation will give a brief overview of Sandia's MESA (Microsystems & Engineering Sciences Applications) microfabrication capabilities and snapshots of the broad microtechnology development suite. The remainder of the talk will give details of new microsensor and micro-device developments, with a particular focus on the micro-chemical analysis systems that utilize those components.

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Microsensors and Micro-Analytical Systems for National Security Applications

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Sandia National Laboratories

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

Presentation Outline

- Sandia's MESA microfabrication facilities and microtechnology developments.
- The surface acoustic wave (SAW) sensor story: discrete microsensors → integrated microsensors → micro-analytical systems.
- Microfabricated components and subsystems for chemical micro-analytical systems. Many applications for national security.
- Toward → fully integrated microsystems.

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Acknowledgments

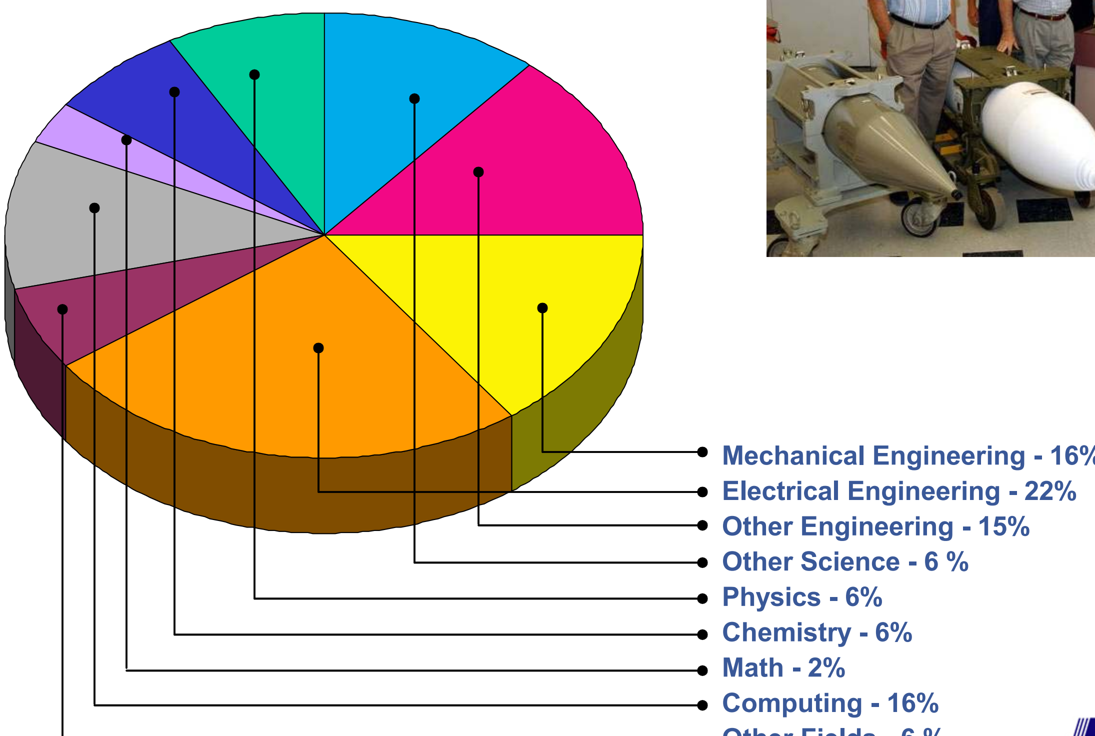
- Literally 100s of scientists, engineers, and technicians contributed to the work presented here. Included are Sandians and many external collaborators.

- This work is funded through a variety of sources: DOE & NNSA, other fed govt agencies, other agencies, CRADA partners.

Sandia National Laboratories

Sandia National Laboratories: Highly Skilled Workforce

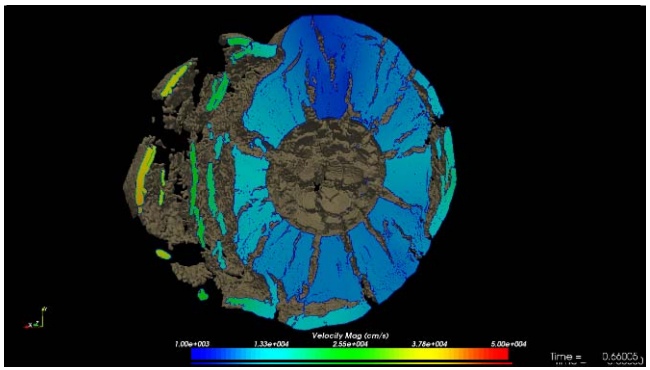
- More than 8,600 full-time employees
- More than 1,500 PhDs and 2,700 MS/MAs
- 2,200 on-site contractors
- $2.33 billion FY06 total budget



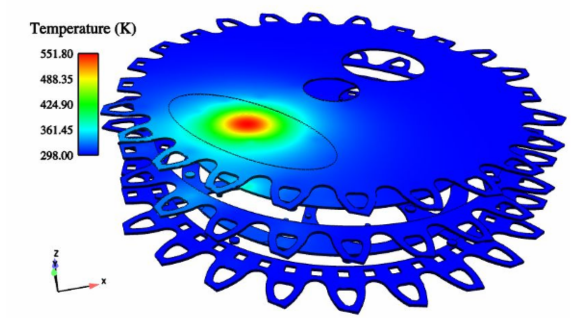
National Nuclear Security Administration

Sandia National Laboratories

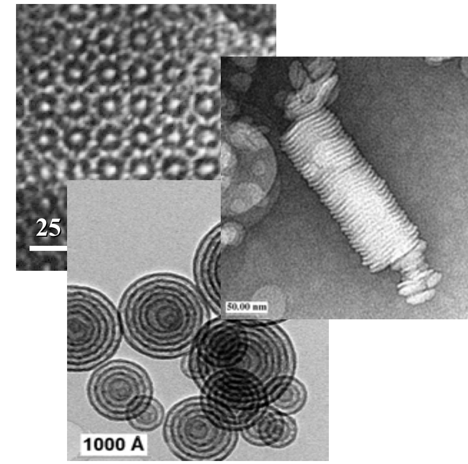
Our Mission Focus Relies on Strong Science and Engineering



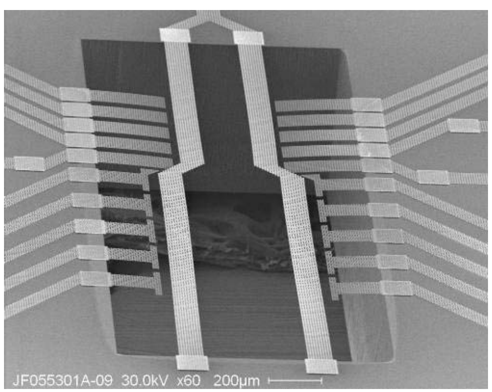
Computational and Information sciences



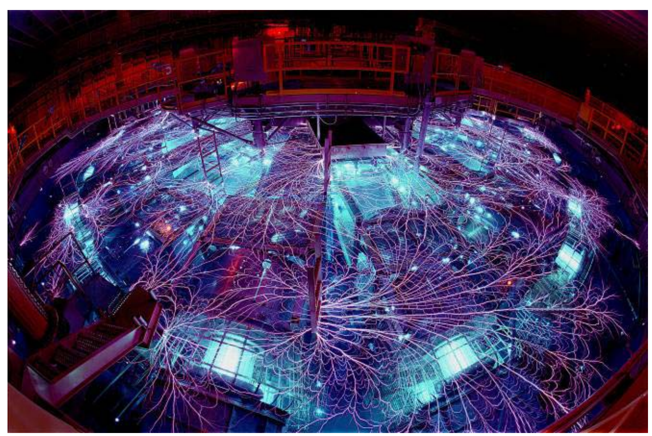
Engineering Sciences



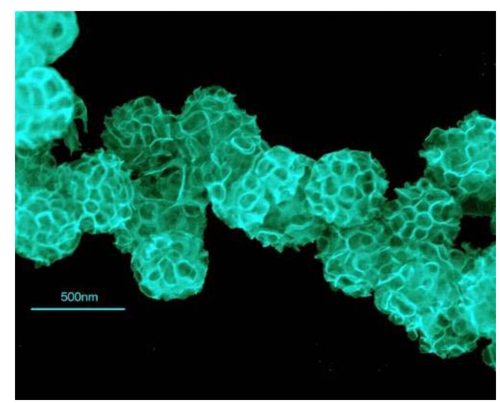
Materials Science and Technology



Microelectronics and Photonics



Pulsed Power



Biotechnology

NNSA National Nuclear Security Administration

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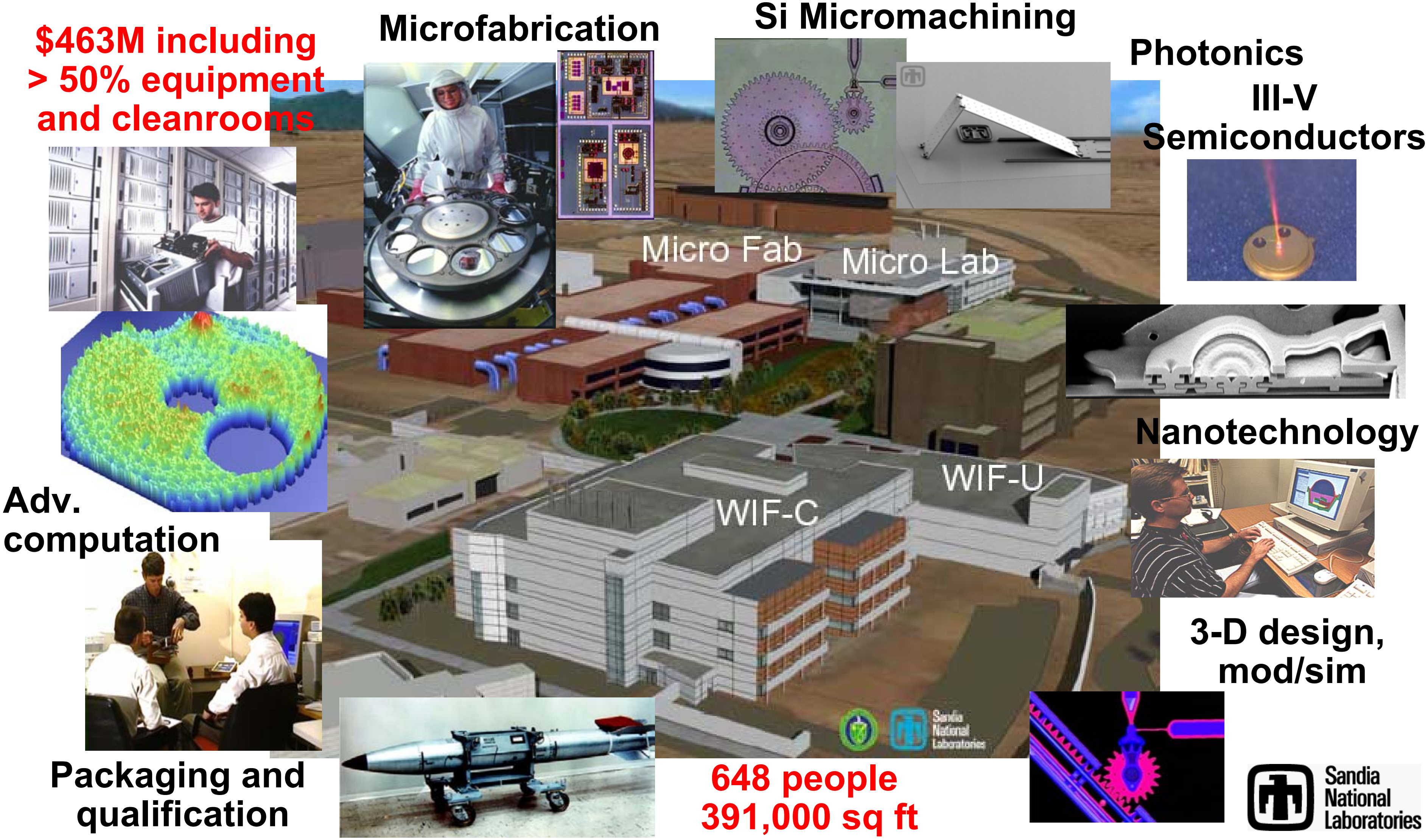
MESA – complete facilities for microsystems design, integration, fabrication and testing



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MESA Microfabrication and Microtechnology Development

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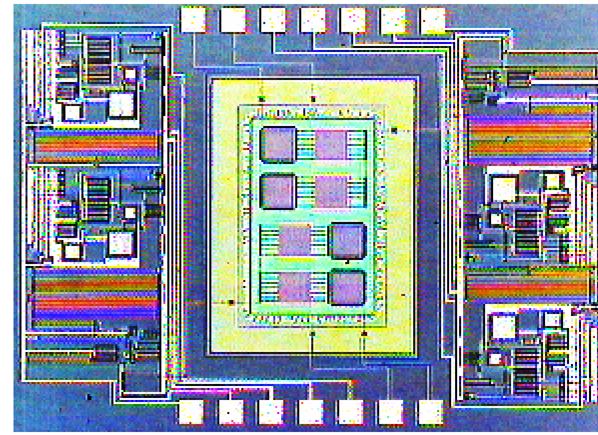
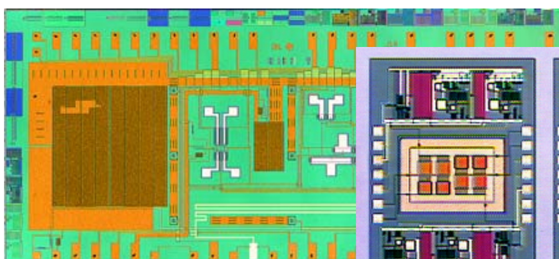
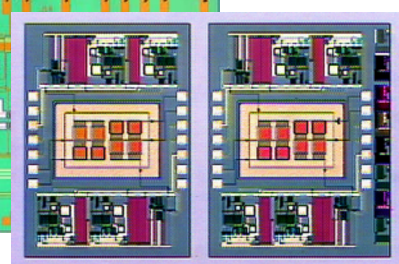
National
Laboratories

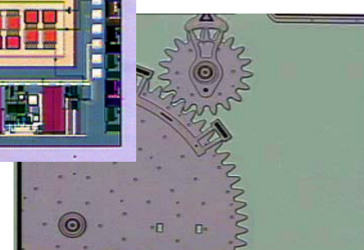
Integrated Microsystems: The Next Technology Revolution

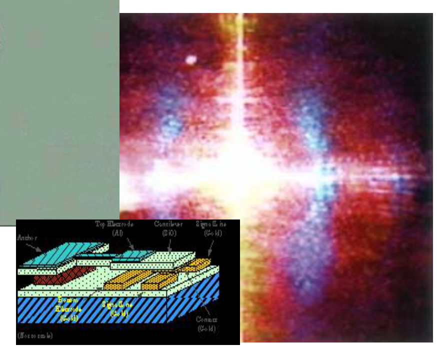
- The next leap in function of Integrated Circuits will involve more than just packing more transistors on the chip
- It will involve combining Si, III-V, MEMS, and advanced packaging technologies to create an integrated capability to :











Sense (physical, environmental, imaging)

Decide (acquire, process, interpret)

Act (MEMS, microfluidics)

Communicate (optical, RF)

… affordably and reliably.

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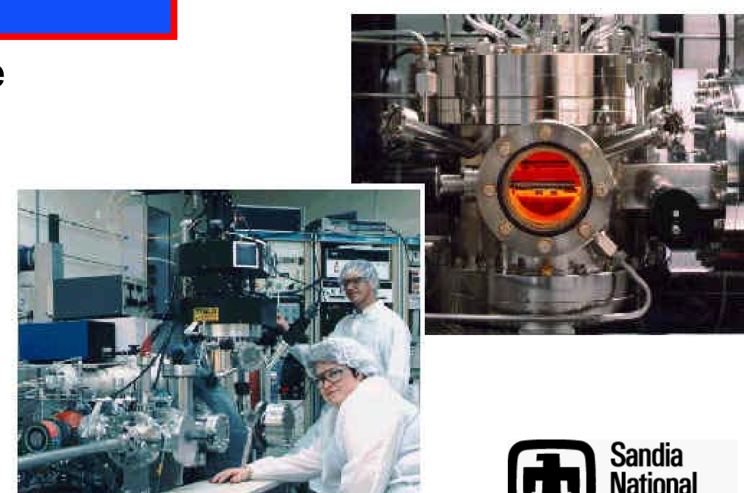
Sandia's MESA MicroFab Facilities

Silicon Fab for Product Delivery (aka, MDL)

- One tool set supports both 350-nm radiation-hardened digital and mixed-signal integrated circuits and MEMS.
- 22 separate laminar flow clean room bays - each with an independent air supply collectively provide over 12,000 square feet of Class 1 clean room space.

MicroFab for R&D (successor to CSRL)

- Approx 10000 square feet of Class 10 clean room space
- Presently supports:
  - Microsystem development and prototyping
  - Compound semiconductor materials growth and processing
  - RF & photonic device technologies
  - Microsensors fabrication
  - Hybrid integration and advanced packaging



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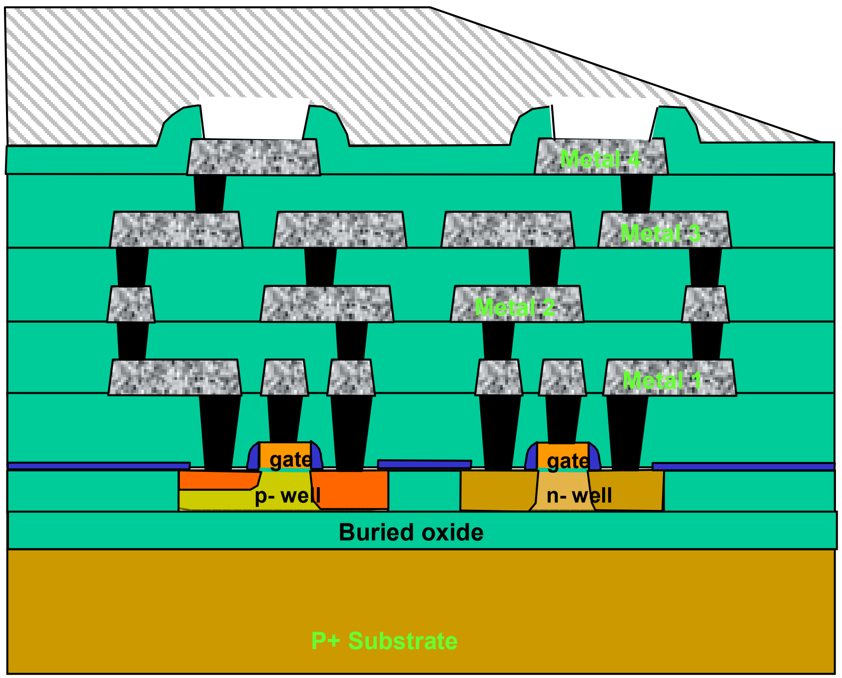
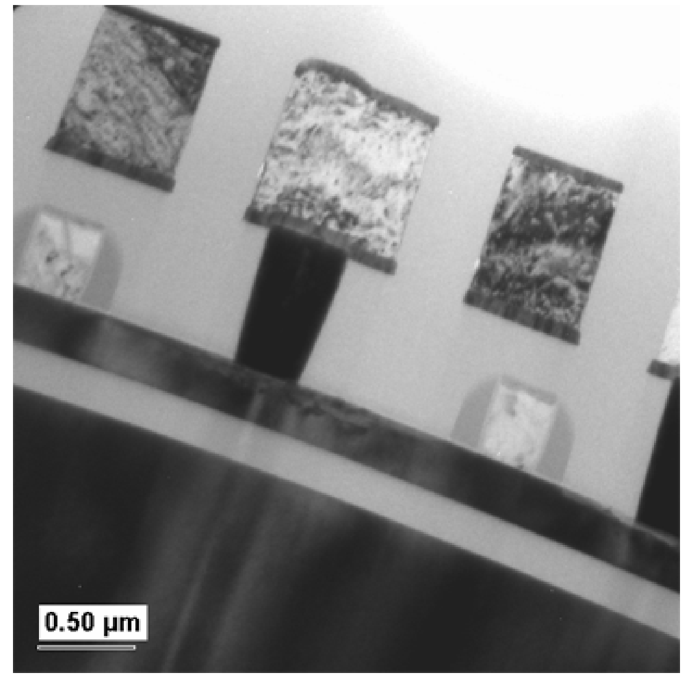
Sandia's Microelectronic Technologies

1. CMOS 7 – 0.35μm SOI





2. Also, CMOS 6 – 0.5μm Mixed Signal

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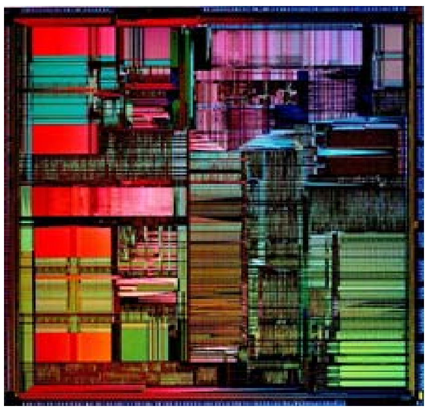
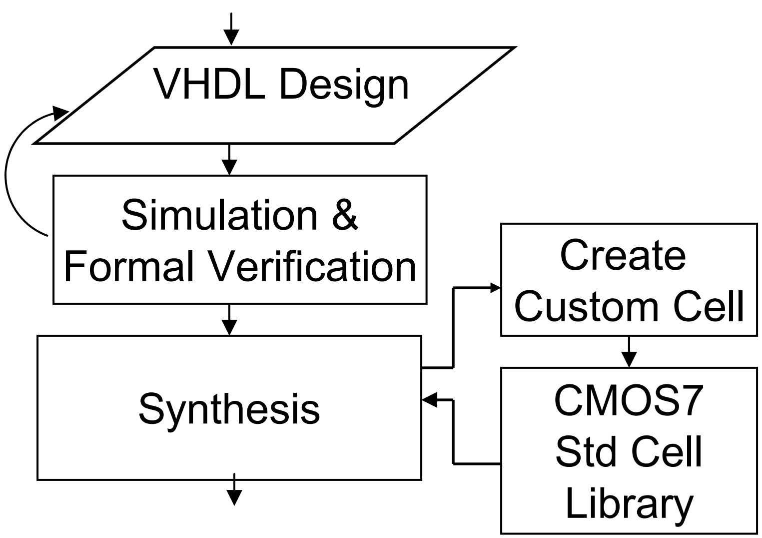
Sandia is Designing, Fabricating, Testing and Qualifying a Rad-Hard Microprocessor





- **Second microprocessor that Sandia has licensed from Intel**
  - ***1980's – Rad Hard 8085* (*emulation)***
- **Pin-for-pin compatible with Intel's commercial version of the Pentium®.**
- **Will be able to survive extreme radiation environments**
  - ***Re-design and re-layout***
  - ***Processing in Sandia's rad-hard SOI CMOS 7 technology***
  - ***Qualification for critical applications***

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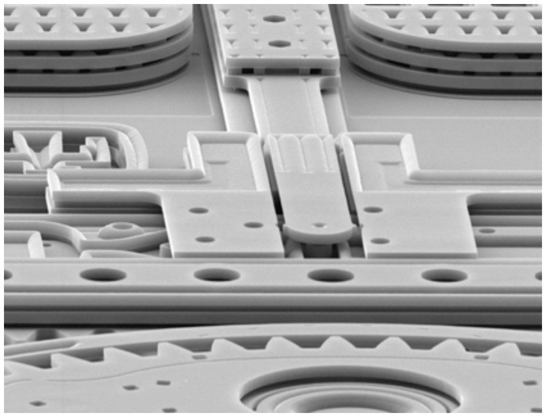
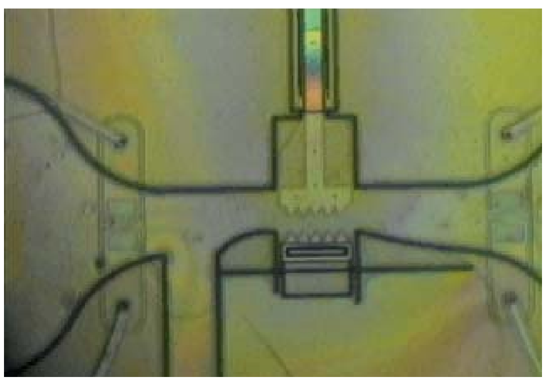
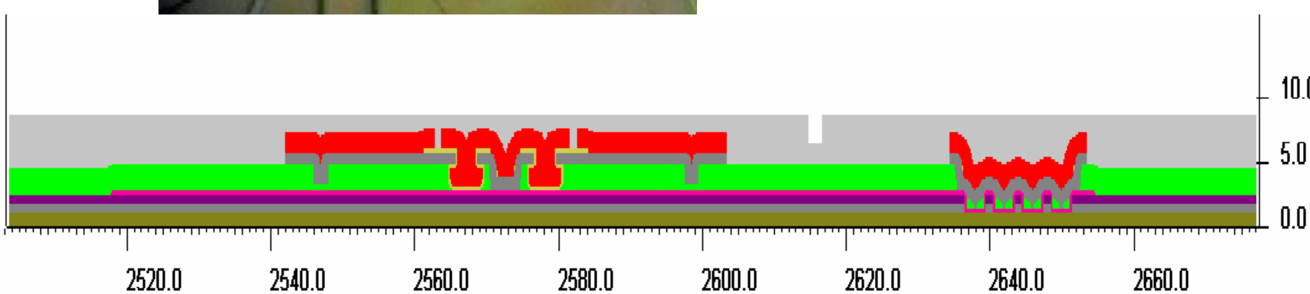
Sandia's Surface Micromachining Technologies

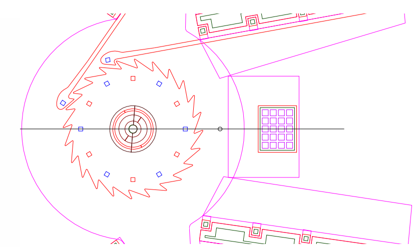




- 5-level surface micromachining technology
- Microfluidics capabilities
- Supporting infrastructures
  - Design tools
  - Reliability
  - Failure Analysis
  - Packaging



Process Simulation



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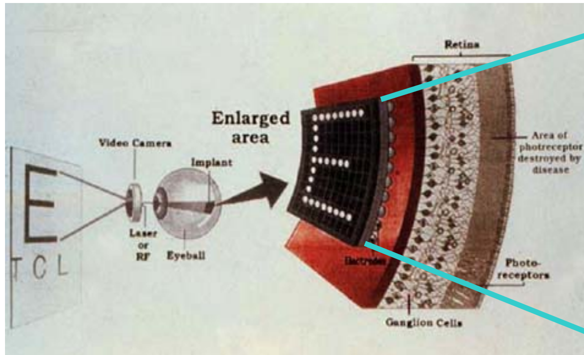
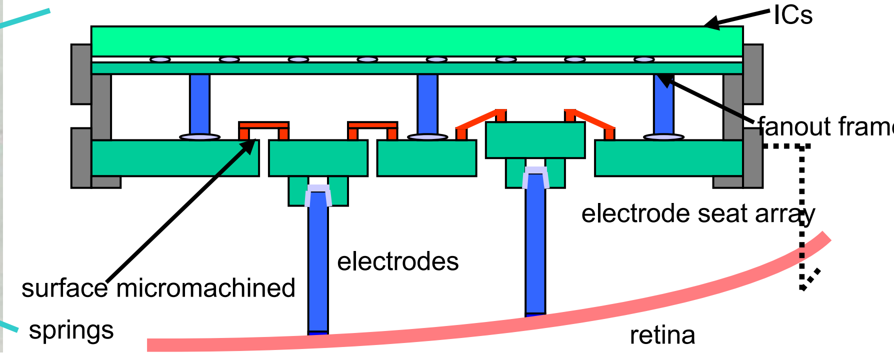
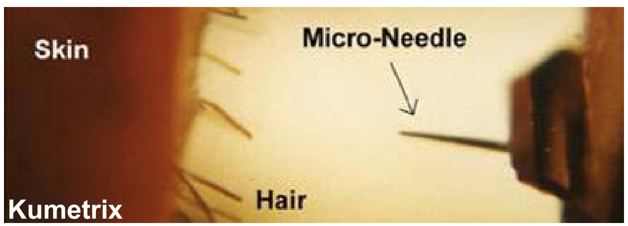
BioMEMS/Microfluidics

Prosthesis:
- neural probes,
- cochlear implant
- retinal implant

DOE Retinal Implant Project
(USC, ORNL, LLNL, LANL, SNL, ANL, NCSU)

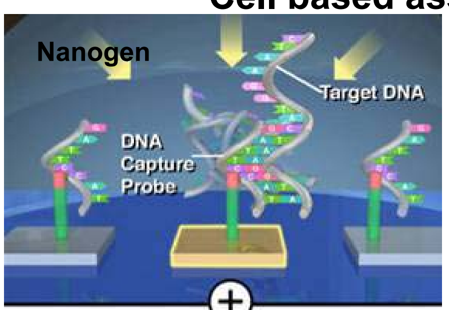




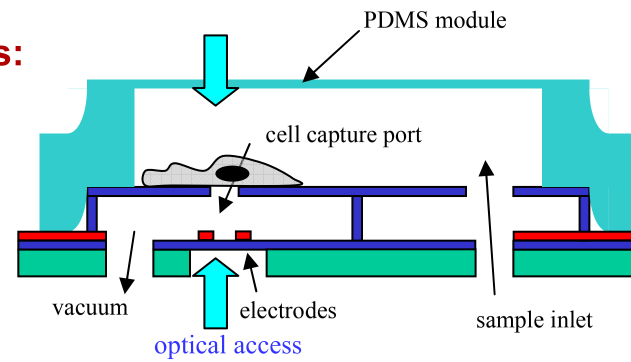


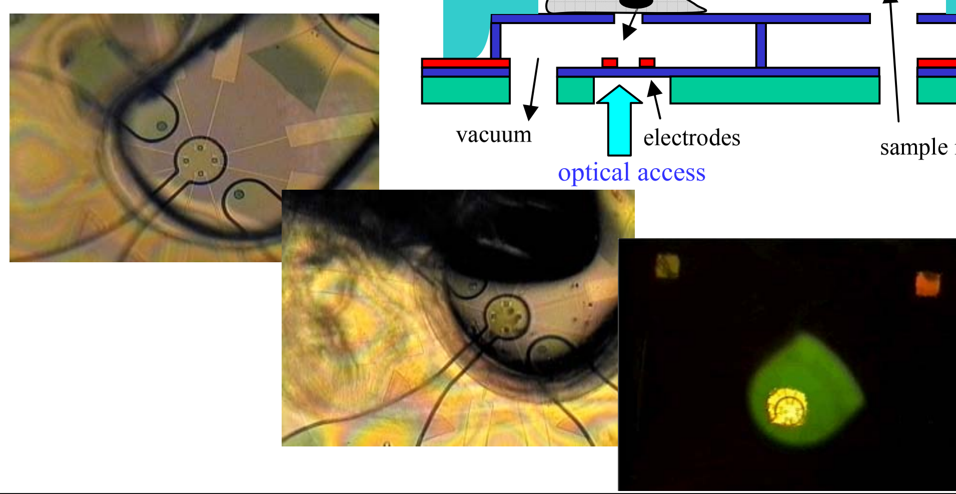
Therapeutic: Drug delivery, in-vivo monitoring

Drug Discovery: Gene chips, Cell based assays



Research Tools/Sensors:
Patch Clamp Array





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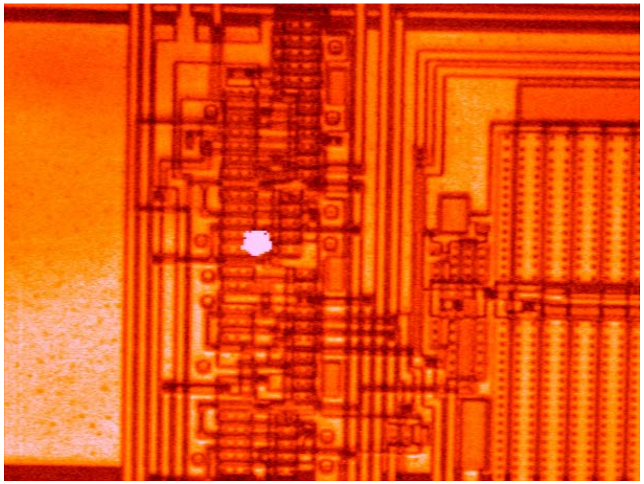
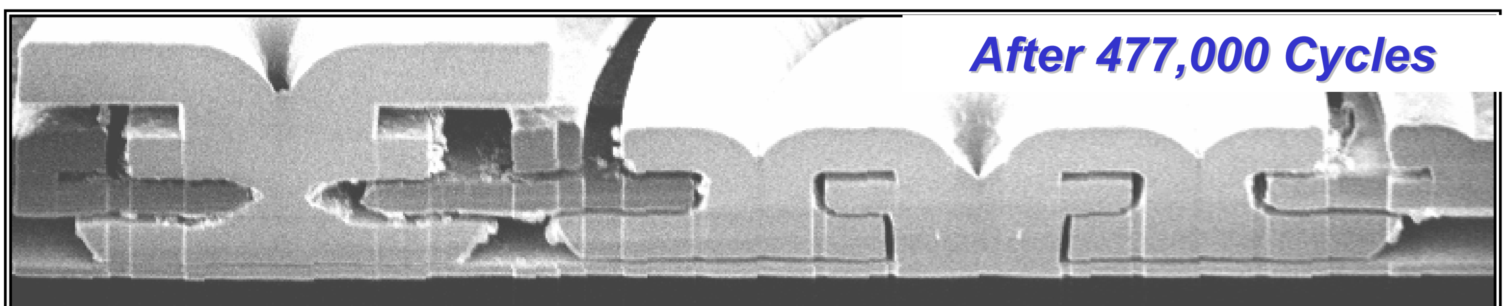
Sandia's Reliability and Failure Analysis Capabilities



Backside Fault Localization (LIVA)

- **Reliability**
  - *Wafer level reliability to IC qualification*
  - *Science-based Reliability*
- **Failure Analysis**
  - *Complete toolset for IC and microsystem analysis*
  - *Developed a suite of rapid fault localization techniques*



MEMS Reliability

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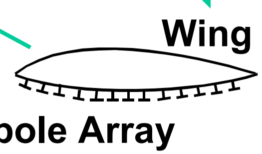
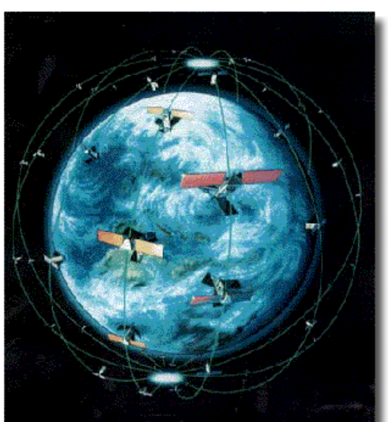
RF MEMS Vision

Conformal Phased-Array Antennas

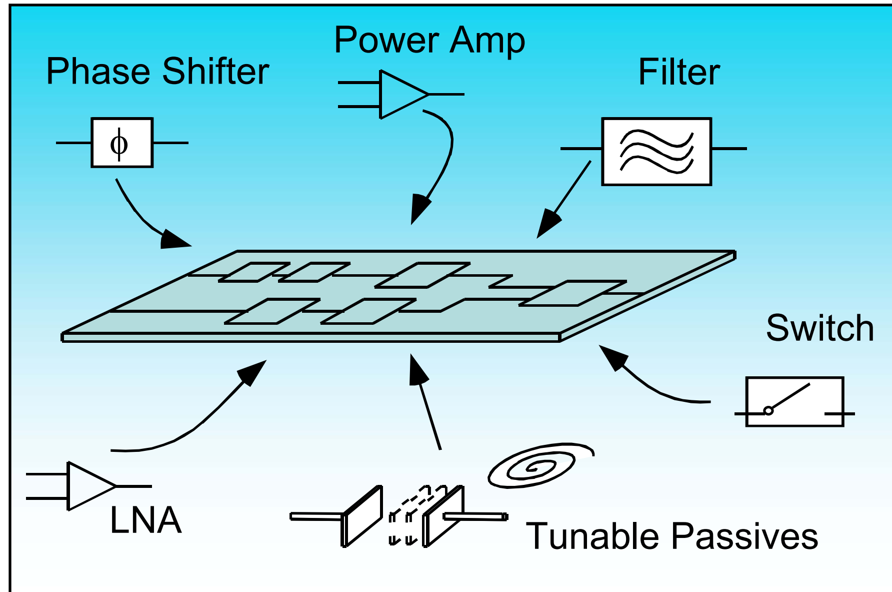


Fuzible Radar for Weapons



Satellite Communications

Integration for performance, size and cost



Surveillance

Misc. Applications:
- Micro-implantable Systems
- UAV's
- Portable ground based communications

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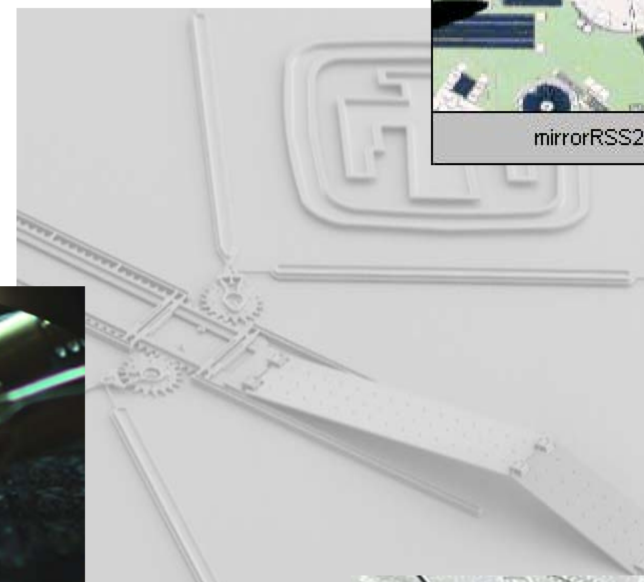
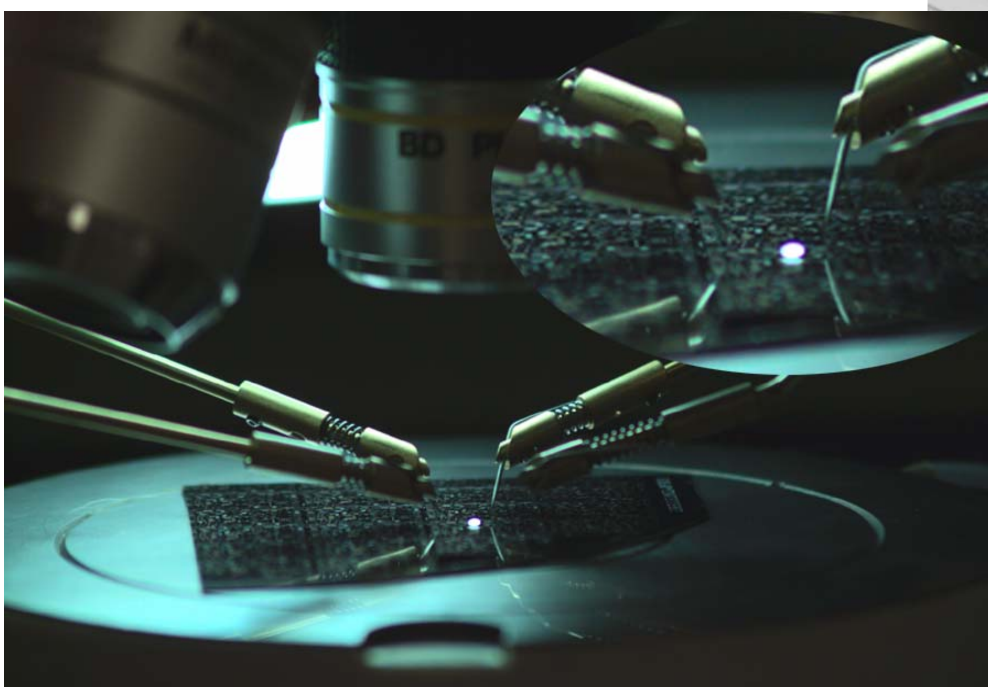
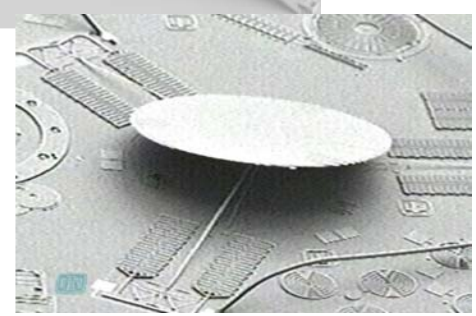
Optical MEMS

Free-space optical switching is currently one of the hottest applications of MEMS.

This capability is expected to enable numerous unique applications in telecommunications and remote sensing.







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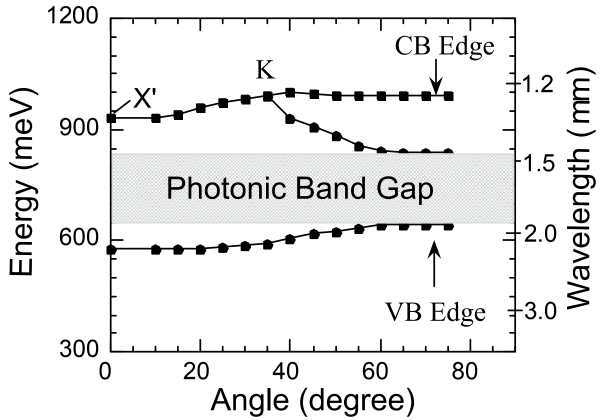
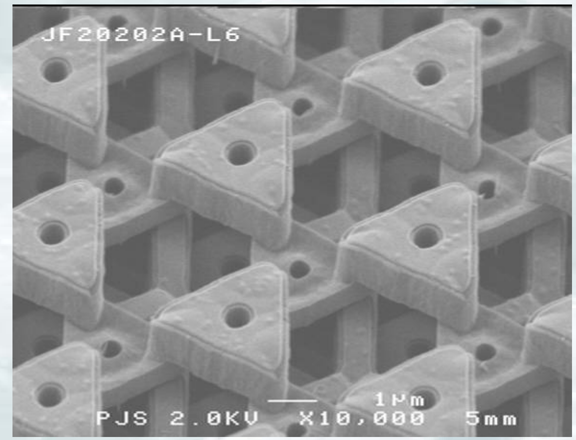
Si 3-D Photonic Lattice Revolutionizing Photonics

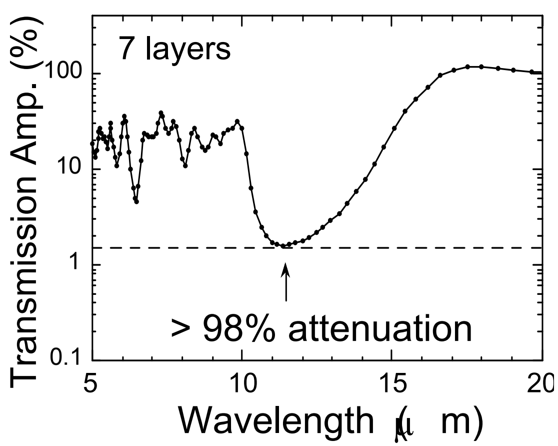
1) Photonic lattices - the optical analogues of semiconductors



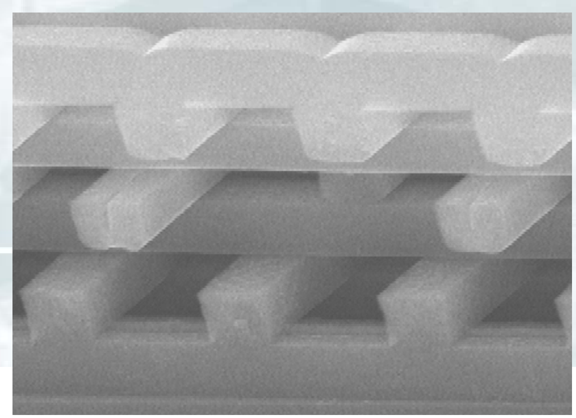
2) Sandia is developing novel Photonic Lattice designs.



3) This enables a high level of control over optical properties.



4) Si processing enables the development of well defined structures.



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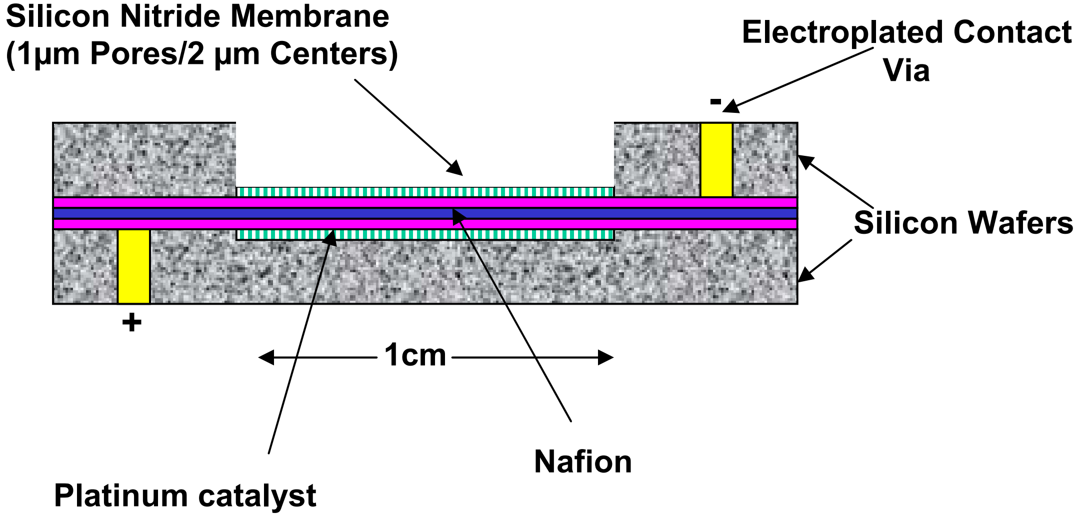
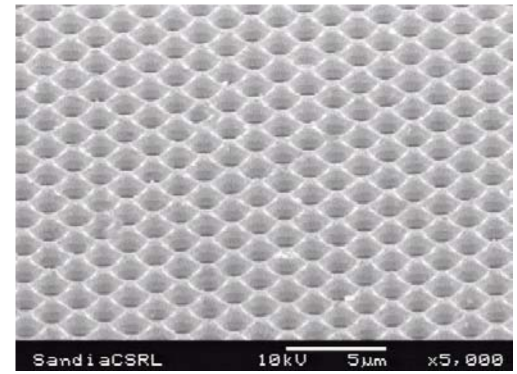
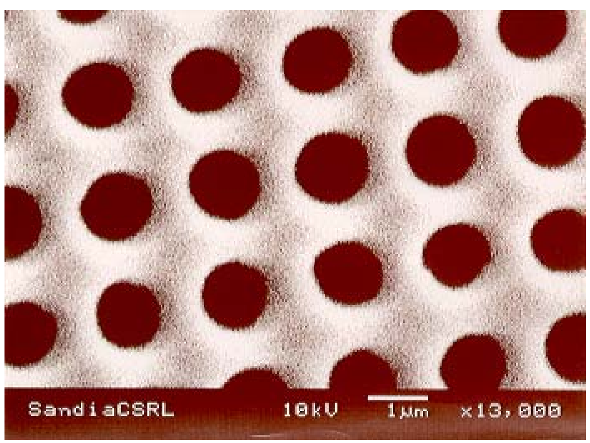
Micro Fuel Cell Technology



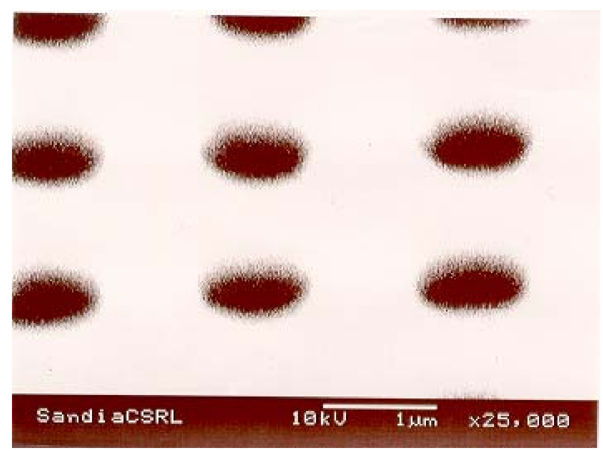
Silicon Nitride Membrane with One Micron Pores and Gold Coating



Lithographically Defined 1 µm Pores on a 1µm Thick, 1cm² Silicon Nitride Membrane



Plan view of 1 u pores.



View of pores at approx. 45 deg angle

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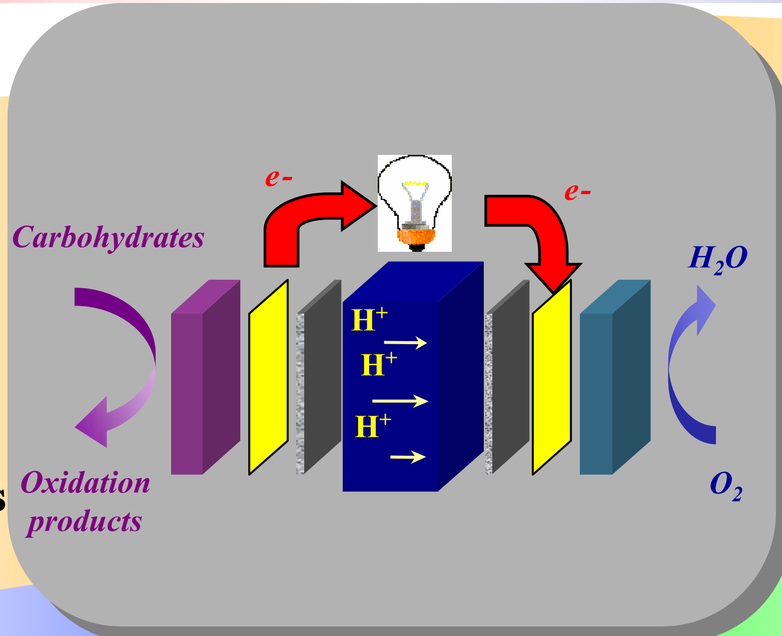
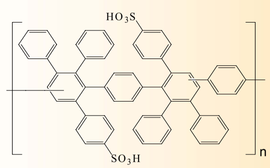
BμFC Component Technologies have Broad Applicability



Membranes



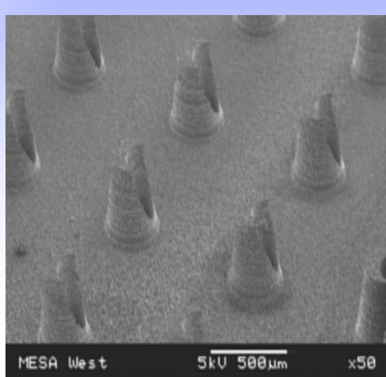
- High Temp Operation
- Mixed Fuel Operations
- Large Scale Fuel Cells

Power Manager ™

- Power Stability
- Energy maximization for long life

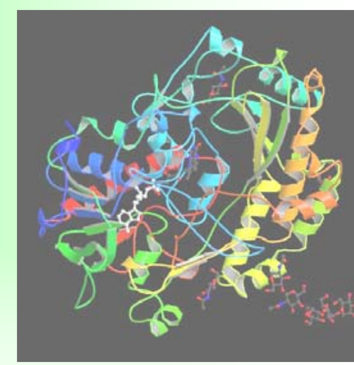
Microneedles

- Front Line Soldier
- First Responder
- State-of-Health Monitors

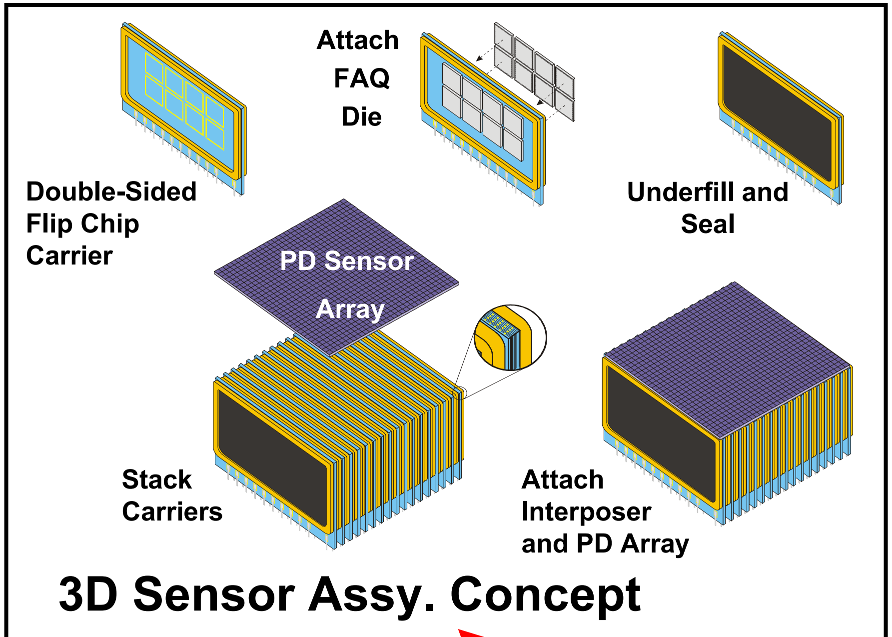


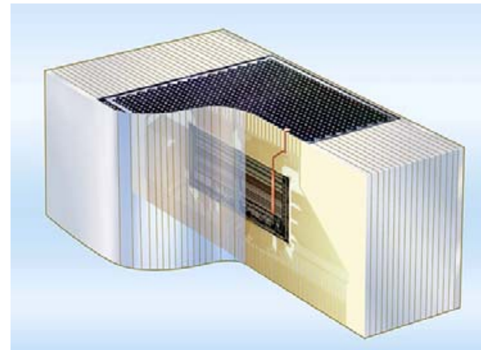
Enzymes

- Chem/Bio Sensors
- Environmental Remediation
- Carbon Sequestration
- Bioreformation

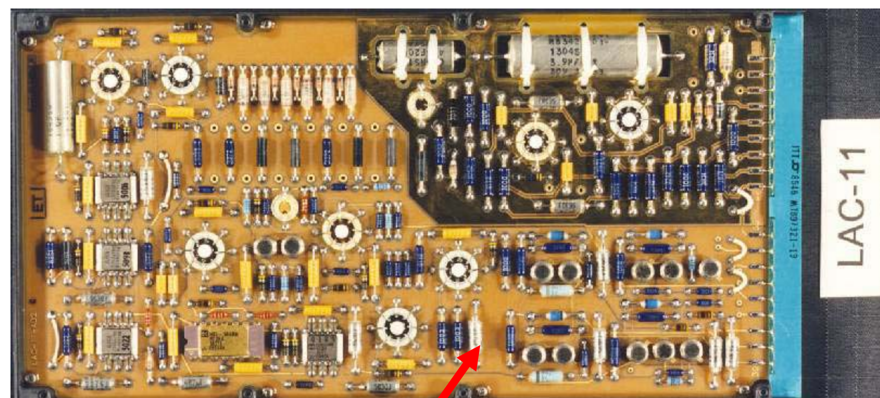


Advanced Packaging for Satellite Optical Sensor Arrays





4096 element optical sensor array and readout assembly



This 4 cu. in. cube will replace 4096 of these PWBs!

2000X reduction in weight & volume

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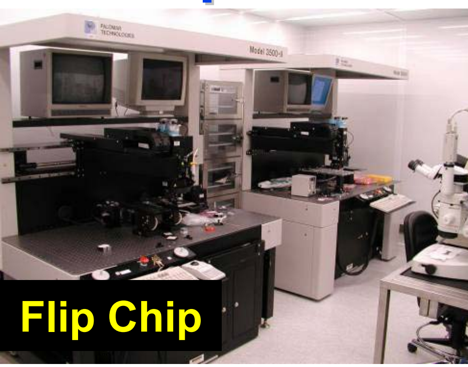
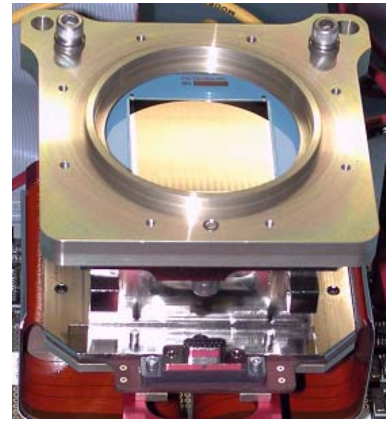
Microsystems Integration Technologies

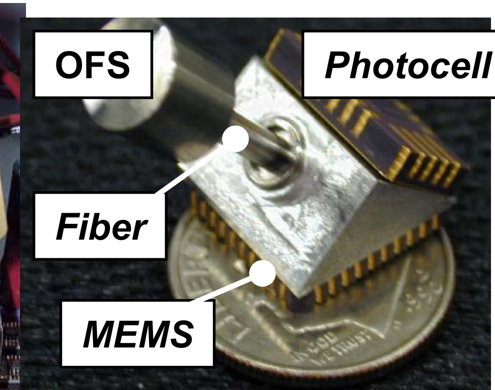
µPAC Facility



- 800 sq. ft. Class 10 cleanroom
- Automated precision die placement and attach
- Flip chip and rework
- Solder reflow
- Real time x-ray system
- Surface Acoustic Microscopy
- Laser profilometer
- Curing ovens and Plasma Cleaner

R&D Areas





- 3-D Integration of Microsystems
- MEMS-based µ-Systems packaging
- Thermal Management
- Ultra-miniaturization and integration
- Ultra-High Reliability Packaging
- Rapid Prototyping

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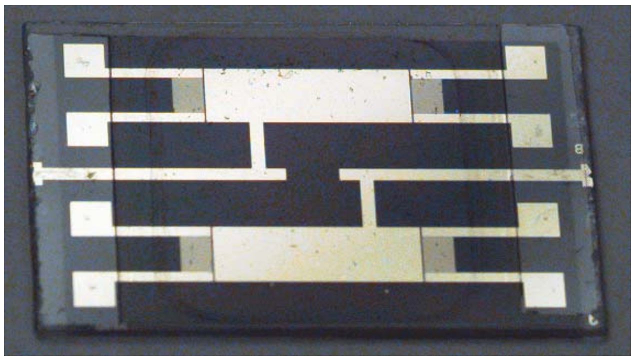
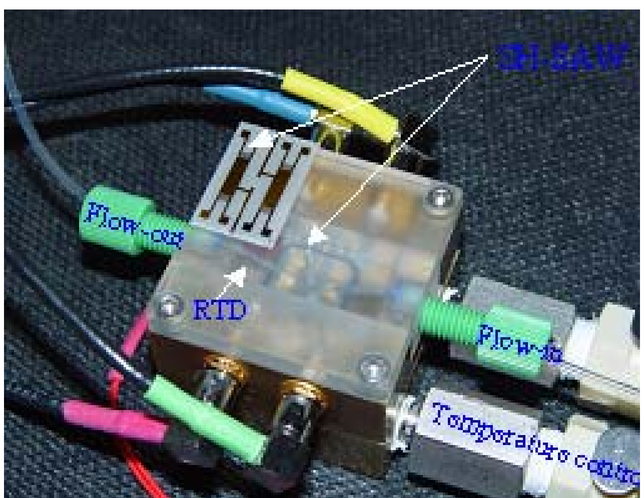
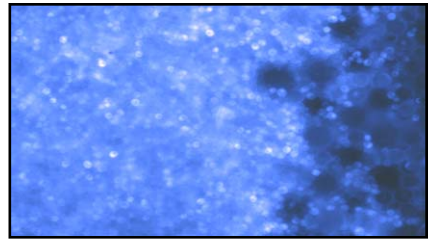
Bio Sensors

Antibody-Coated SH-SAW

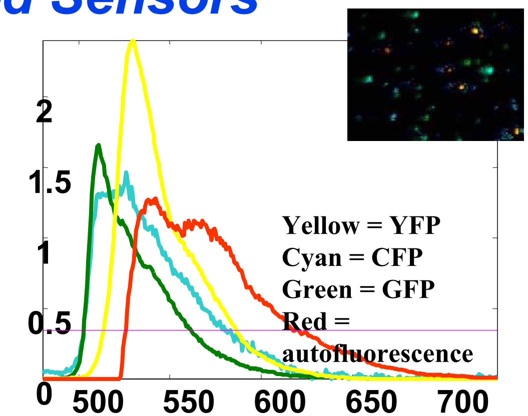




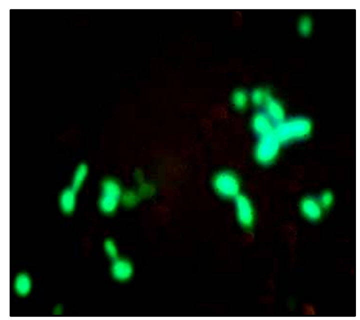
Cell-Based Sensors



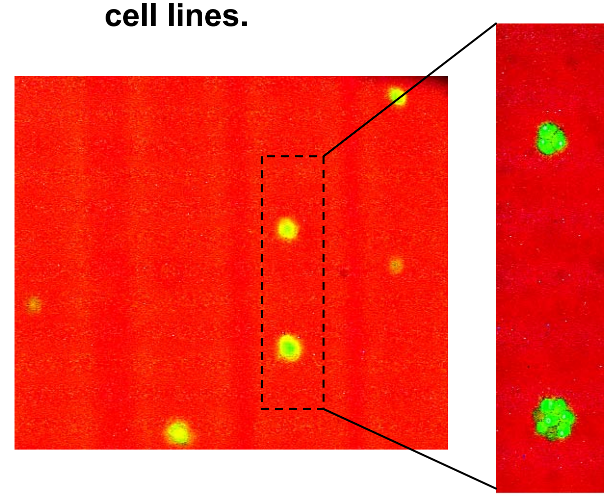
Response of cells (blue fluorescence) to environmental stimulus in a MEMS fluidic channel



Spectral resolution of three different cell lines.



UV Fluorescence



Optically patterned array of cells in biocompatible sol gels expressing GFP

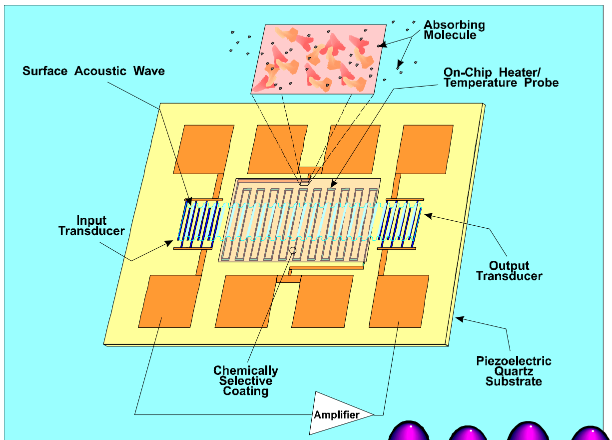
Micro-fluidics Sensors

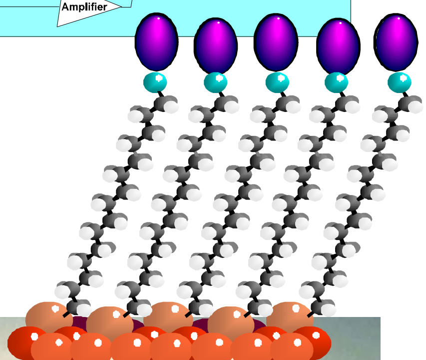
Sandia National Laboratories

The SAW Sensor Story

Sandia National Laboratories

Surface Acoustic Wave (SAW) Gas/Vapor Sensor





- Waves excited in piezoelectric quartz probe mass bound to surface
- Surface film binds selected gases/vapors
- Portable system includes sample handling and electronics
- SAW sensor and oscillator circuitry integrated on GaAs

Applications:

- Organics (solvents, refrigerants, dielectrics)
- Non-proliferation (DOE/NN-20)
- Pollutants (DOE/EM-50)

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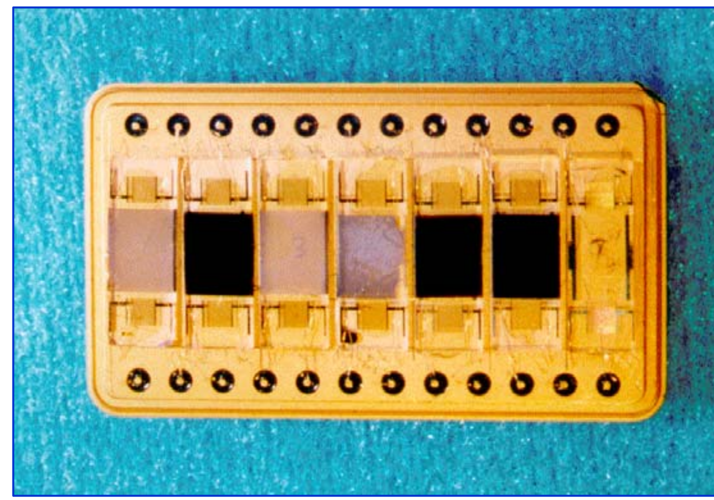
Array Selection for System Implementation

- Optimization analysis suggests best sensor films based on chemical selectivity
- This list used to select films for the prototype sensor array. Also considered were
  - Availability of materials
  - Response sensitivity and stability
  - Response time and reversibility

Category	Coating
High-surface-area	Au (electroplated)
High-surface-area	Pt (electroplated)
Dendrimer	VIIIb, 45% AEEA
High-surface-area	CuO (conversion)
Polymer	PECH, poly(epichlorohydrin)
Bare quartz	None
Polymer	SE30, poly(dimethylsiloxane)



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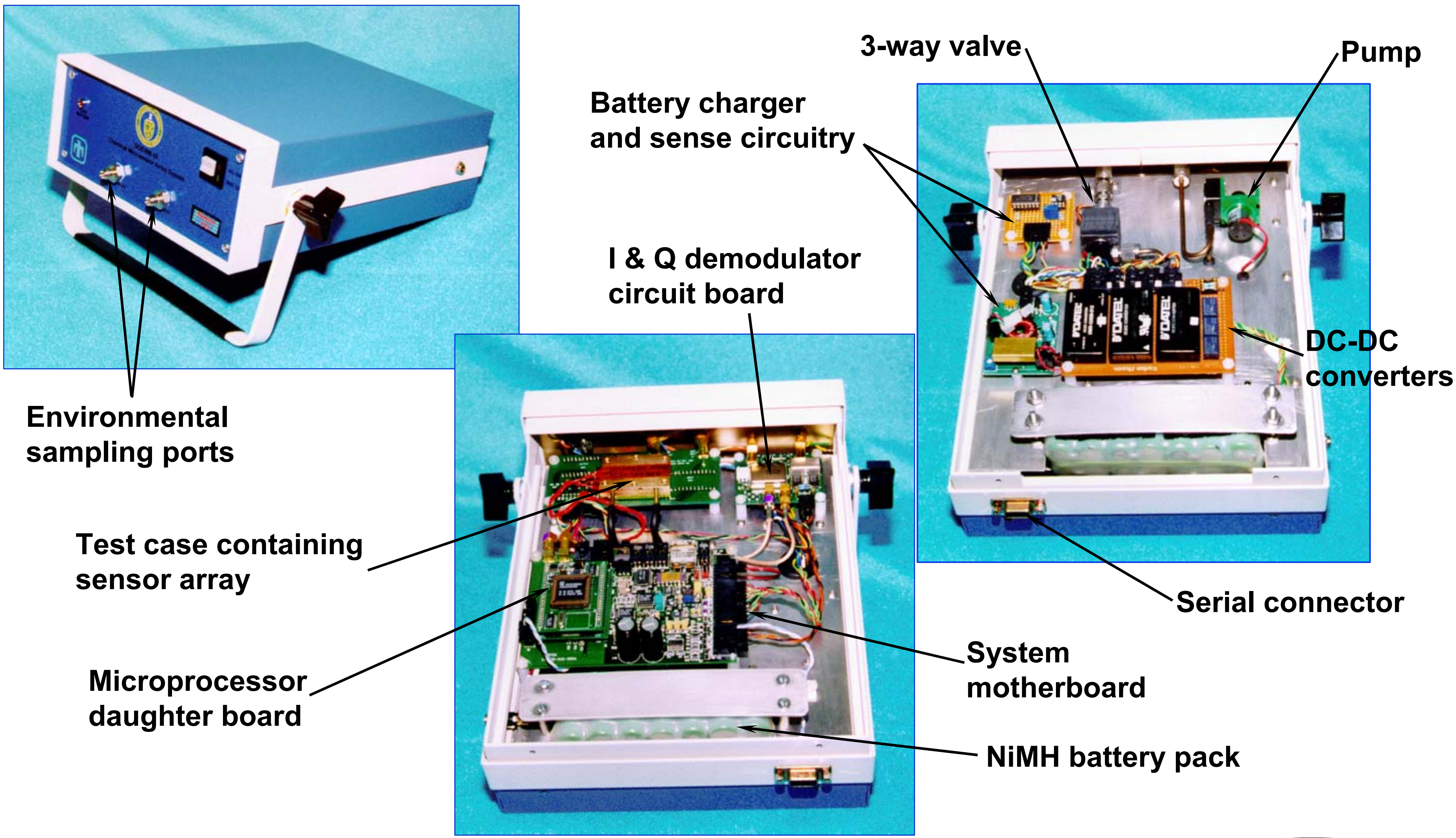
Prototype Sensor Array System



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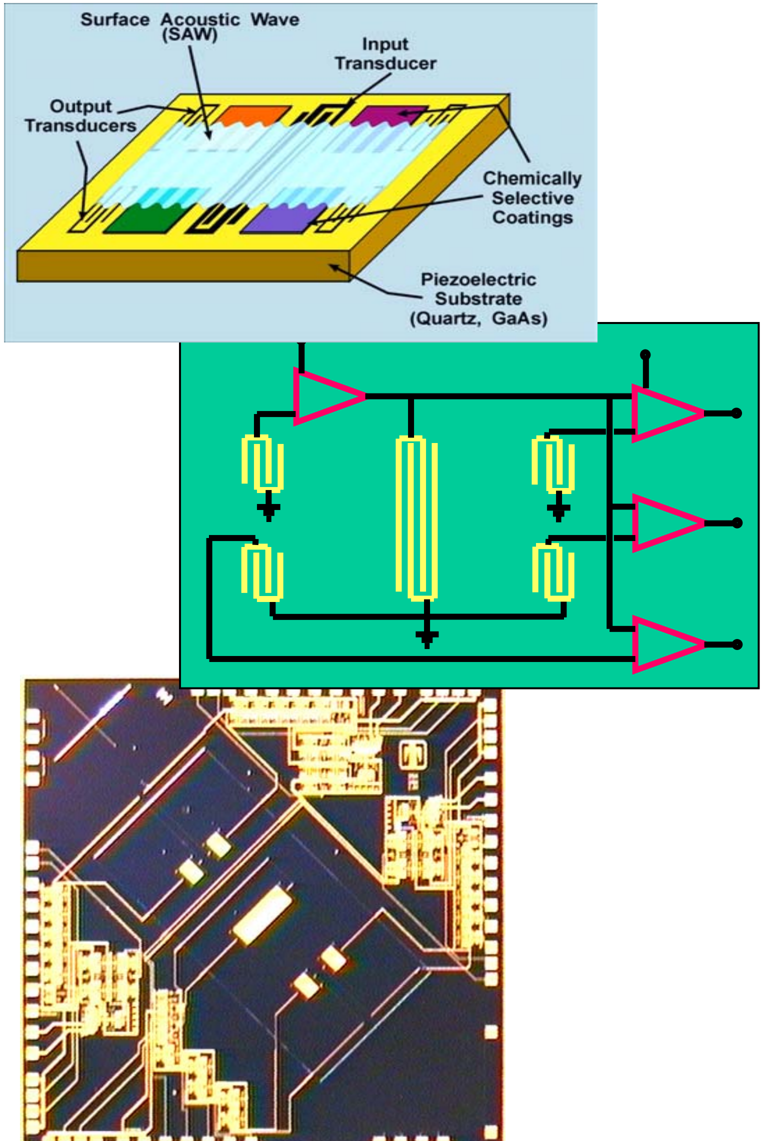
Integrated Surface Acoustic Wave Gas /Vapor Sensor



- Waves excited in piezoelectric substrate probe mass bound to surface
- Surface film binds selected gases/vapors
- Sensor array provides multiple analyte discrimination
- Sensor array and RF microelectronics monolithically integrated on GaAs substrate
- Provides chemical detection in a hand-held unit

<u>Application</u>

- Non-proliferation (DOE NN-20)
- Pollutants (DOE EM-50)
- µChemLab™

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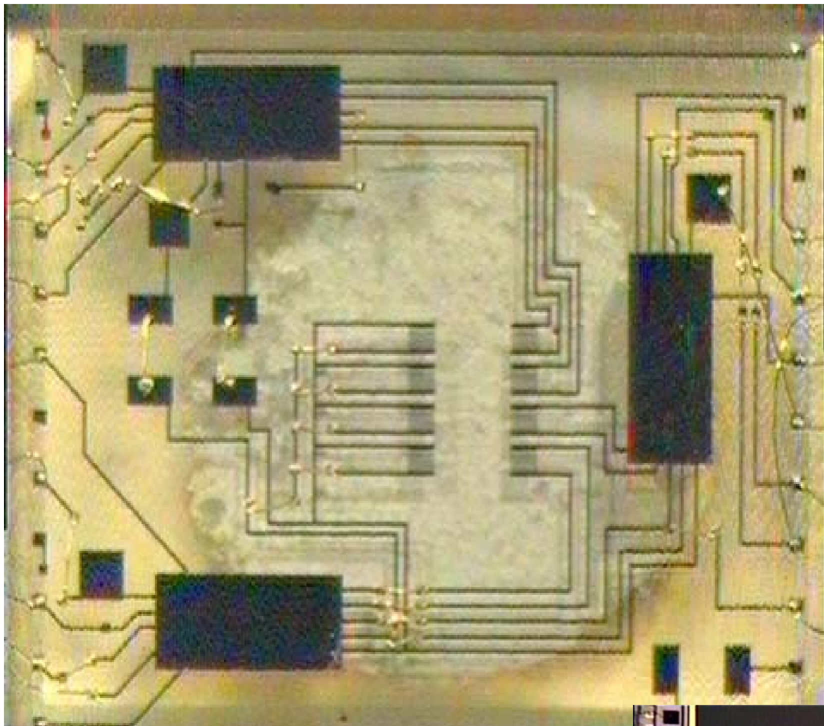
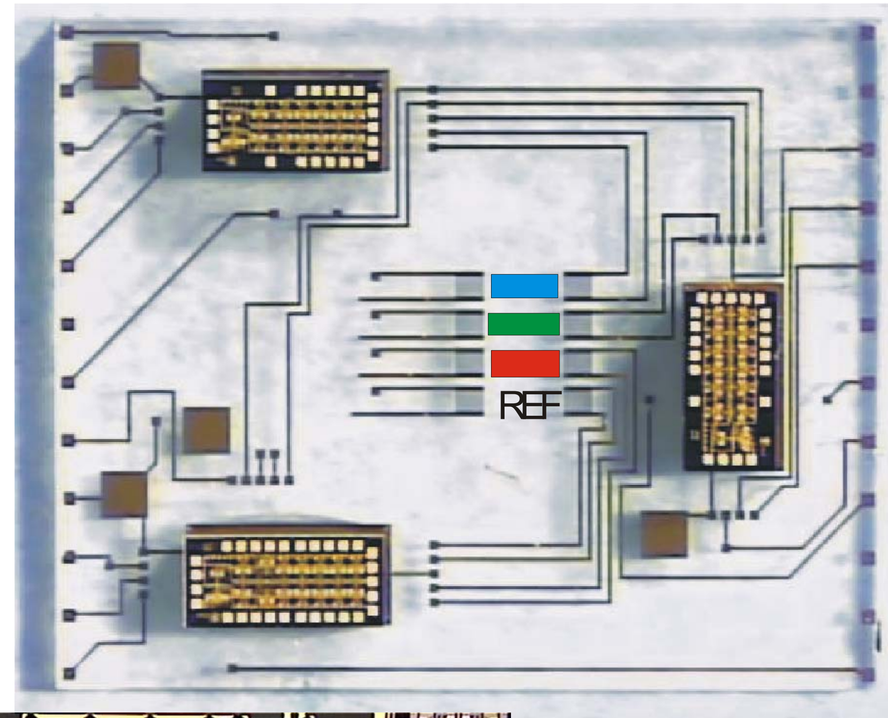
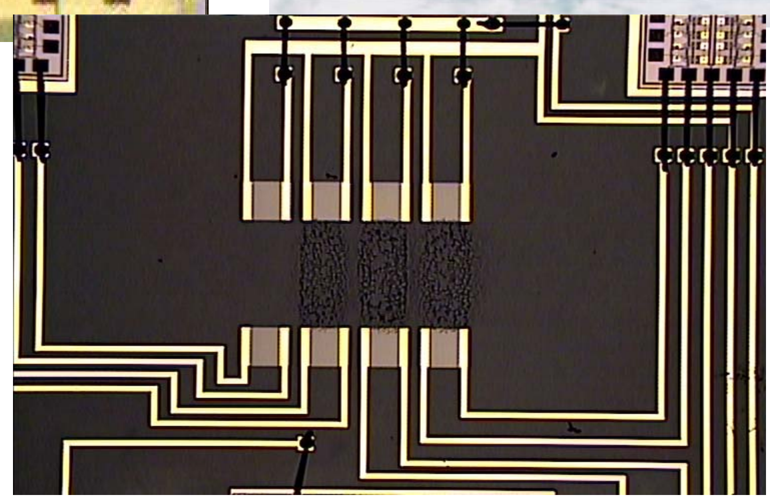
500 MHz SAW Devices







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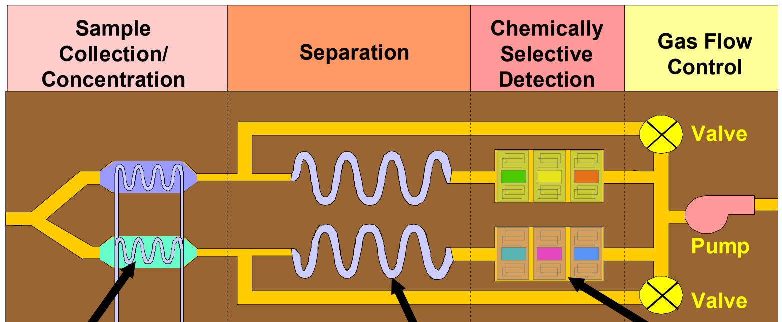
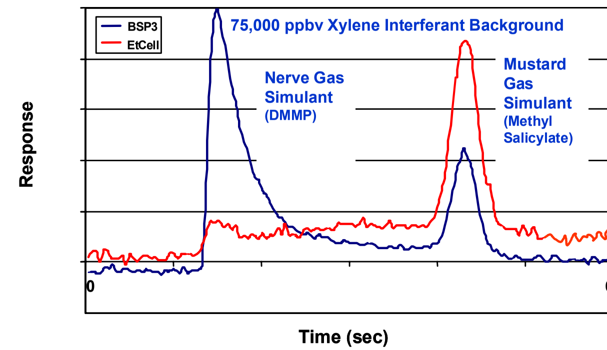
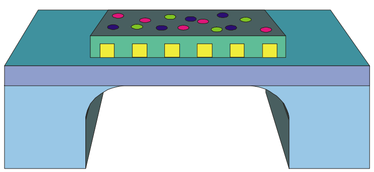
Gas-Phase *μChemLab*™

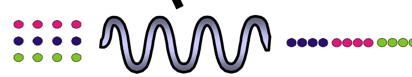
Hand-held chemical analysis system that uses three microfabricated stages.

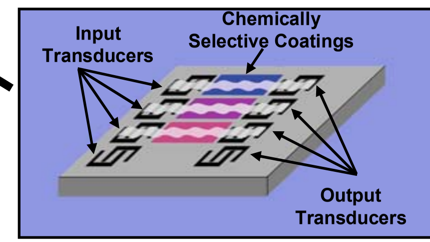
- 8”x4”x2”
- 2 min. analysis
- 4W max. power







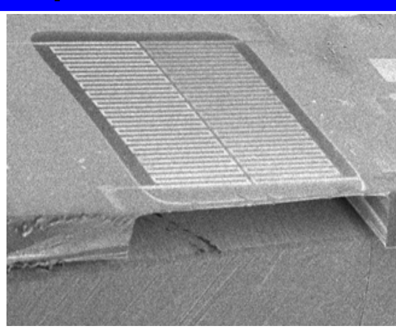


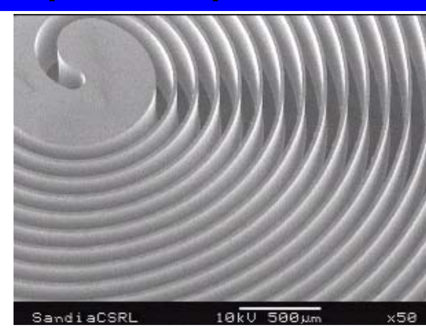


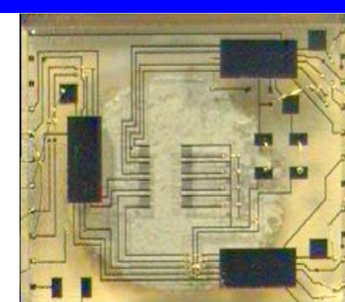
Preconcentrator accumulates species of interest

Gas Chromatograph separates species in time

Acoustic Sensors provide sensitive detection







Sandia National Laboratories

Micro-Chemical Analysis Systems

Micro-Chemical Analysis System Architecture

point detection/analysis systems

front-end components

- environmental sampling
- extraction, derivatization, pyrolysis
- self-check, calibration

basic analytical system functions

- sample concentration
- analyte separation/ gas chromatography
- chemical detection

- pumps & valves
- fluidic interfaces
- thermal control

- electronic control
- I/O & user interface
- power supply

back-end components

- sensor network
- larger system integration

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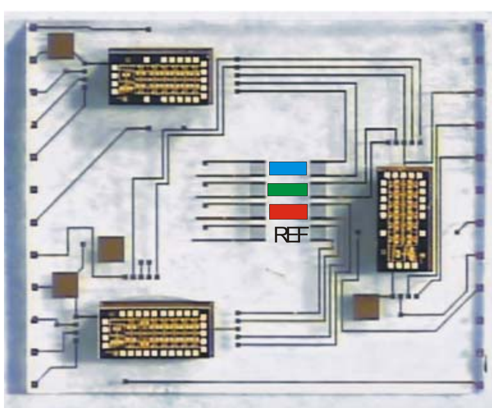
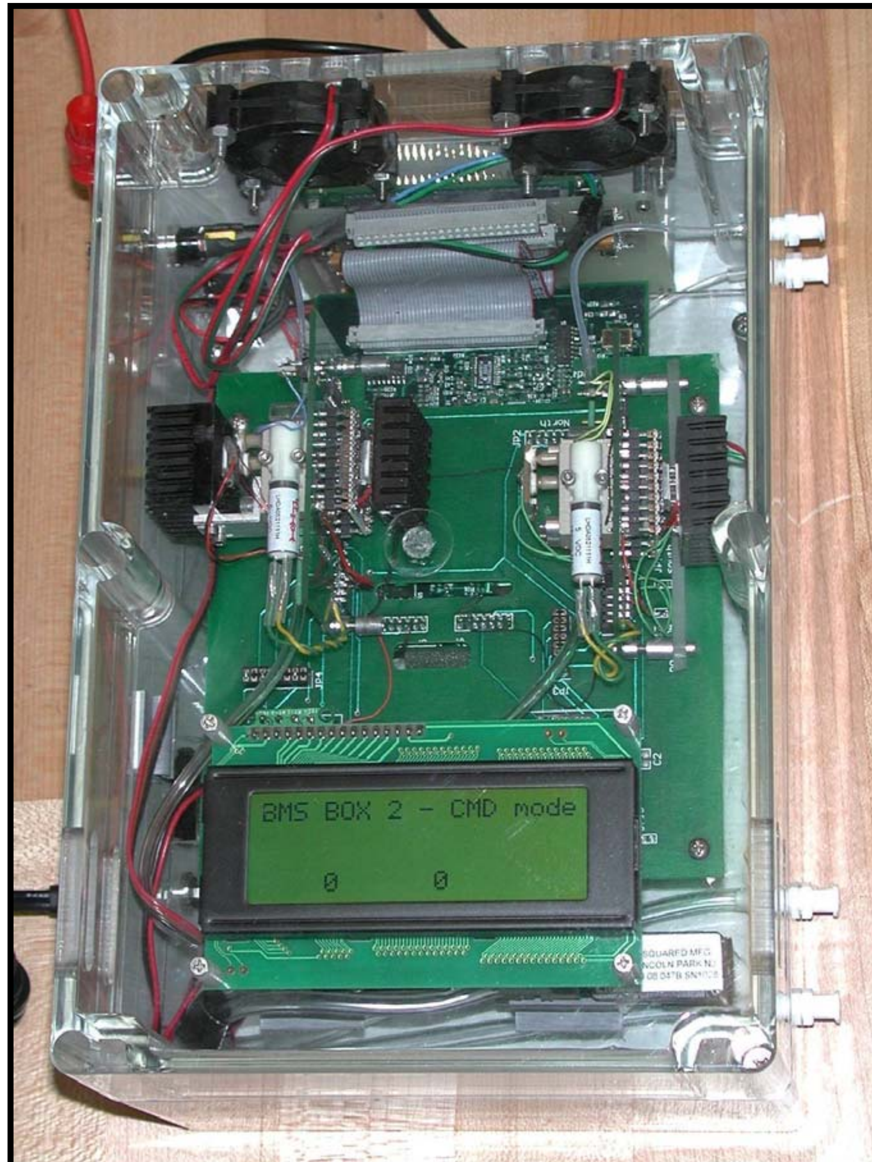
Hand-held Version of Gas *µChemLab*™





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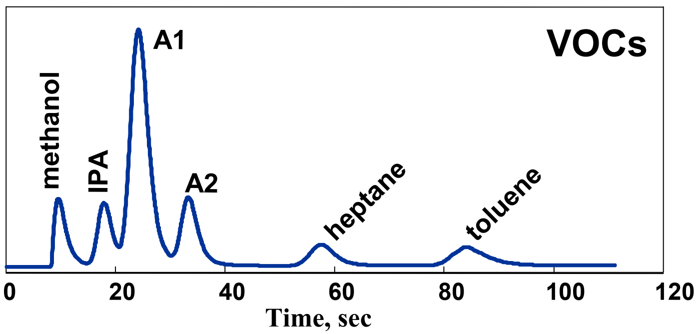
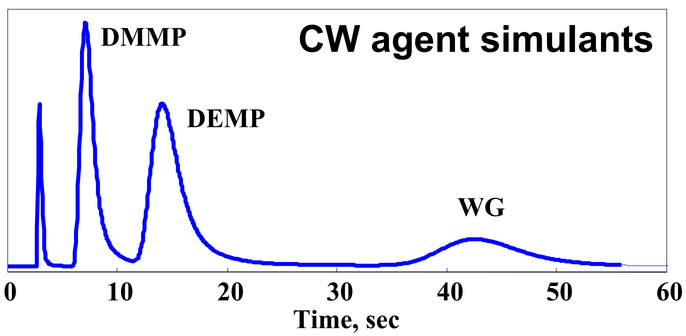
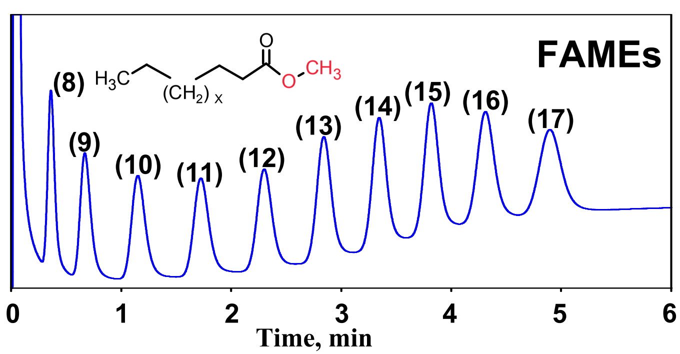
μChemLab™ has Broad Applicability







μGC-*Columns Tailored to Specific Applications*

- Light gases: CO, CO_2, C_1-C_4
- Pharmaceutical drying, VOCs
- Chemical warfare agents/simulants
- Biological analysis, FAMEs

Specificity Achieved by

- Specific material coatings or packings
- Column length
- Rapid temperature cycling

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Prototypes Tested & Delivered to DoD Customers

- Full performance prototypes:
  - System: single channel, 3-SAW array, GC heating ramp, 2-minute analyses.
  - Custom software: programmable GC heat control, data logging and data replotting, peak search and peak integration
  - Other specs: Wt ~ 2 lbs.; Power ~ 4 W, 4 to 8 hrs on Li-ion battery pack.
- Agent testing → demonstrated detection at significant concentrations, including GA, GB, GD, GF, Vx, HN3, HD.

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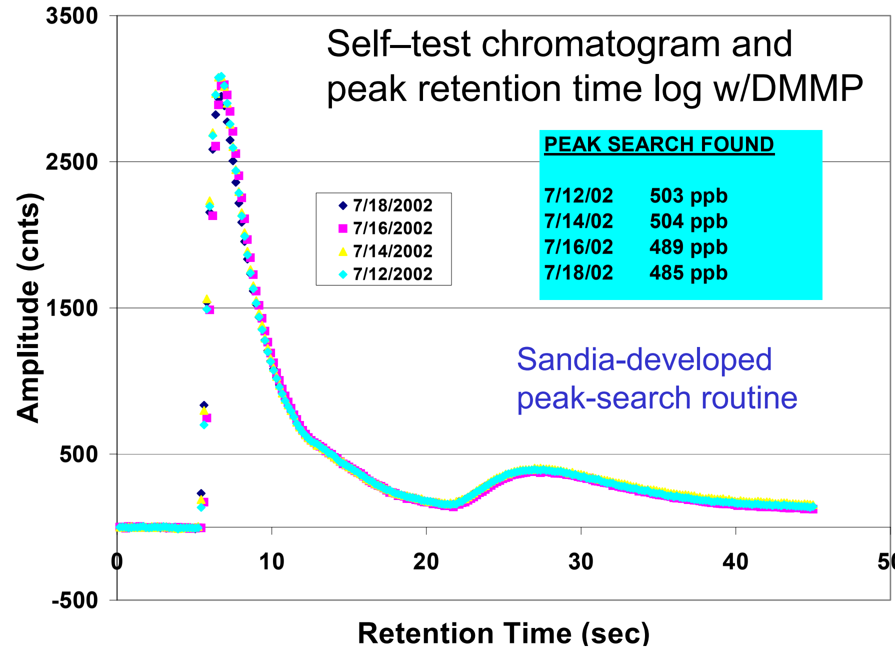
μChemLab™ Systems Installed In Test Beds – Airports & Subways

- Improved temperature control
- Durable pumps
- Gas chromatograph for false positive reduction
- Flexible method development
- Test results show analyses are very stable



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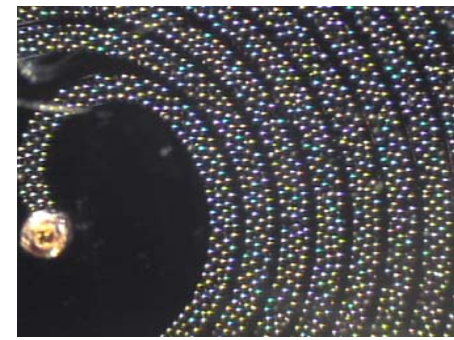
Industrial Process Monitoring & BTU Analysis

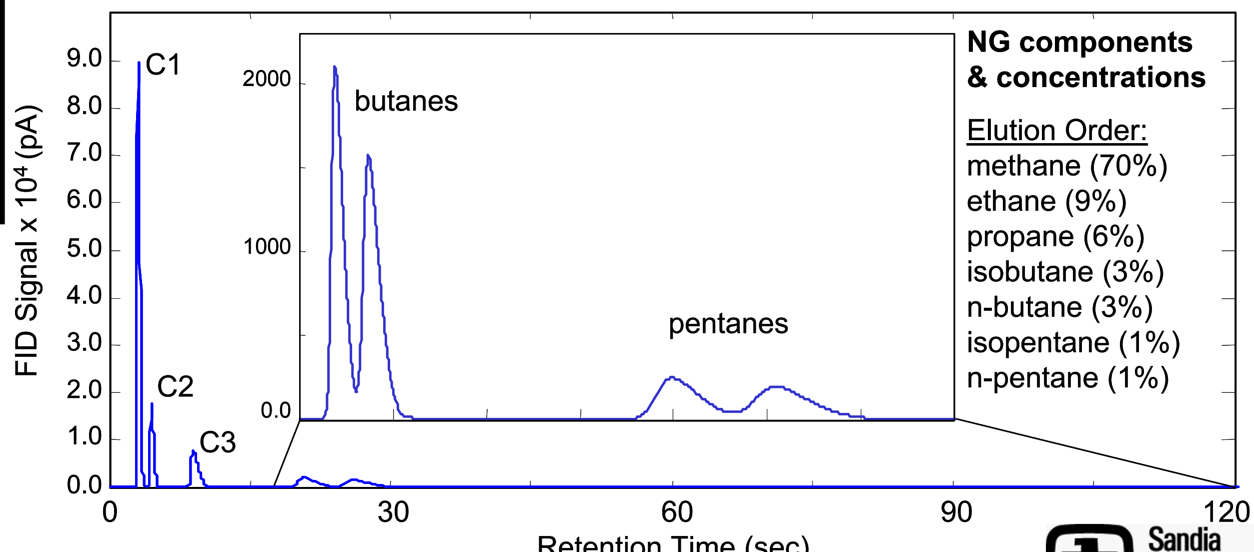
<u>Separation of Natural Gas</u>

Packed column:
300 μm wide x 300 μm deep x 20 cm long

Haysep B packing

Isothermal operation 100 C;
20 psi carrier pressure

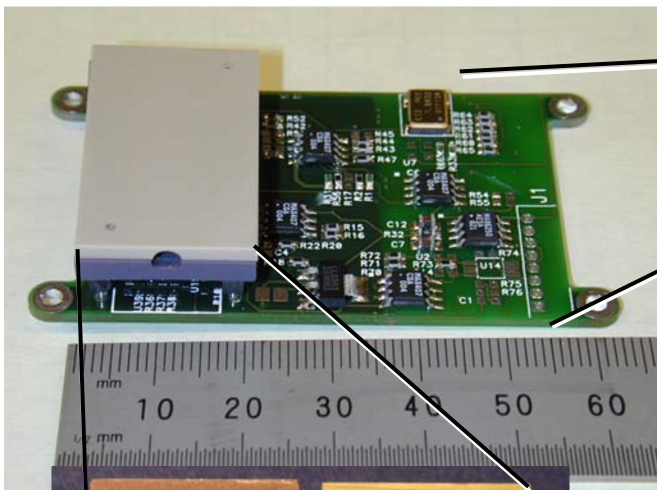


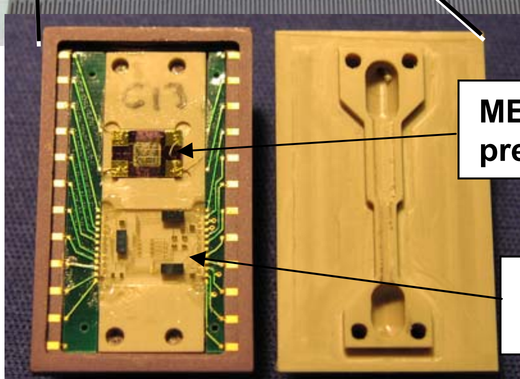


Sandia National Laboratories

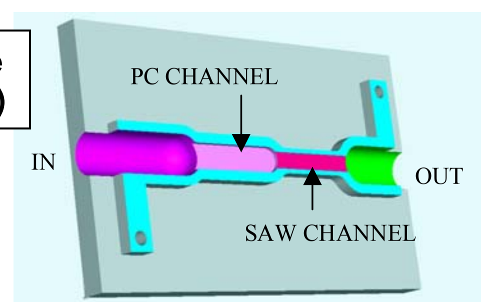
SnifferSTAR^{TM} –
Chemical Sensor for micro & mini-UAVs
Developed in conjunction with Lockheed Martin

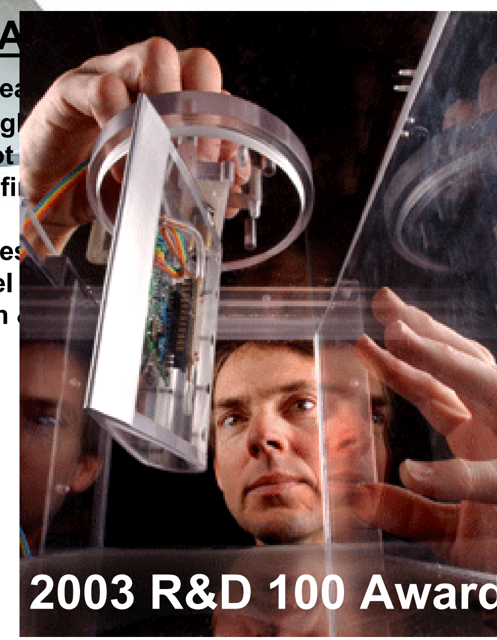
System parameters:
- **light weight: ~ 16 grams**
- **low power consumption: ~ 0.5 W**
- **15 to 20 s processing time**
- **nerve & blister agents**





Silver Fox Mini-UA
- **Deployed by battalion lea**
- **Flies 500 to 1,000 feet hig**
- **20 lbs., 8 feet long, 6 foot**
- **Detachable wings & tail fi golf bag**
- **Launched from a compres**
- **Runs on Glo-Fuel (model**
- **Office of Naval Research Research**

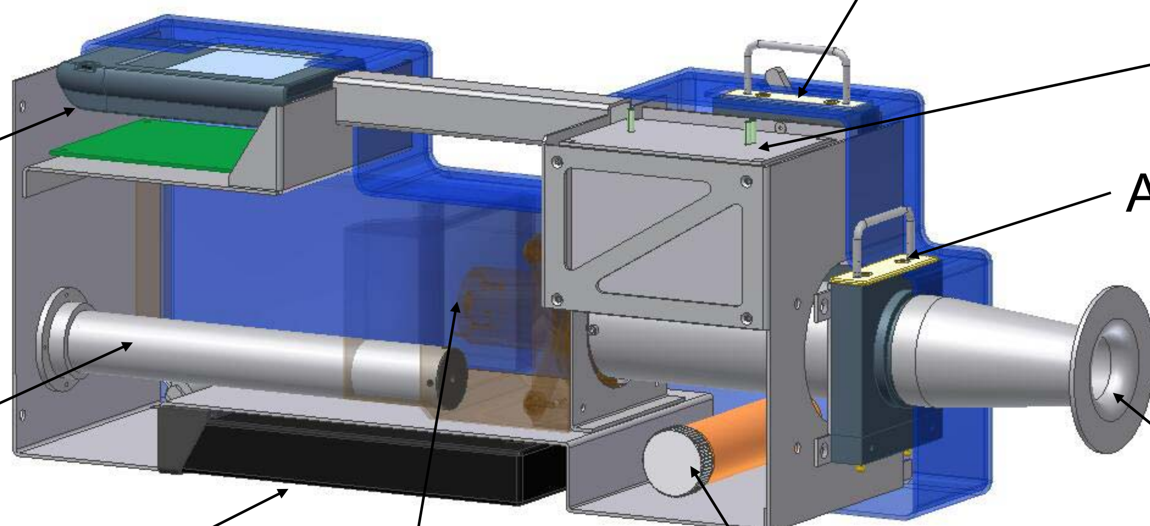




Sandia National Laboratories

MicroHound™ Explosive Detector

- 24"x10"x8"
- <12 lbs
- 4 Hrs (on single battery charge)
- Reports "Go/No-Go" or Detailed analysis (composition, concentration, etc.)



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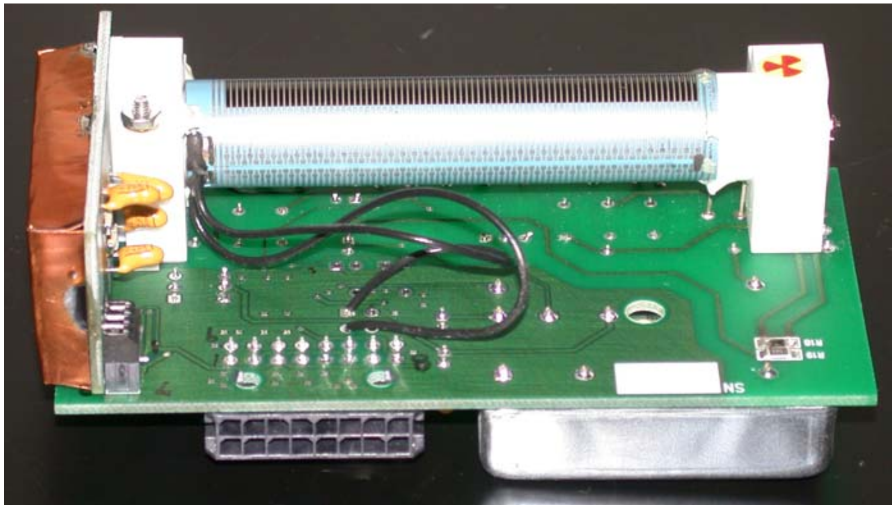
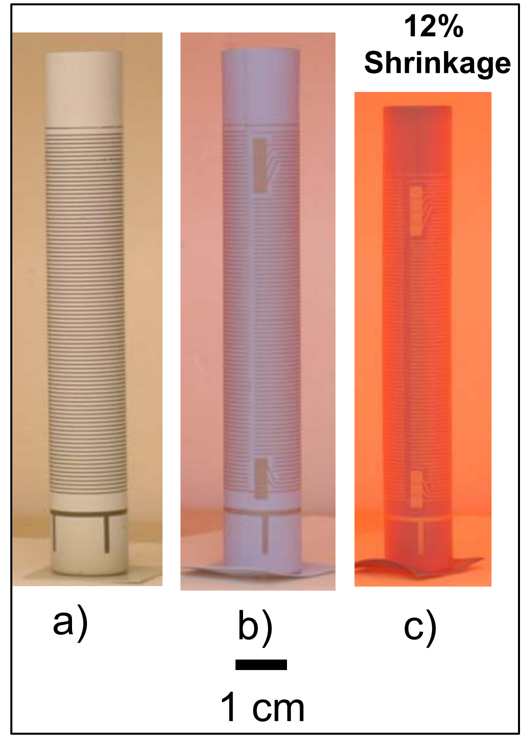
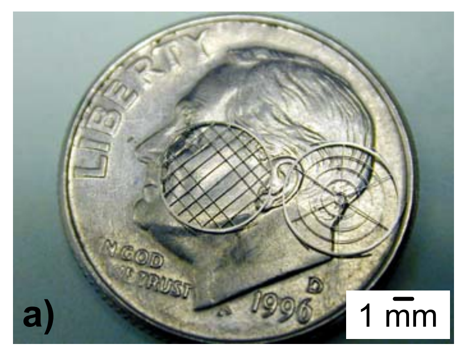
LTCC μIMS Detector



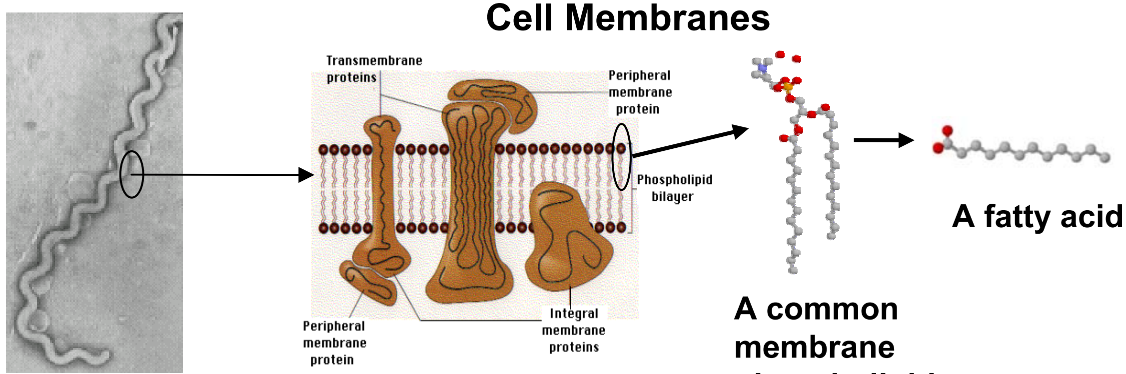


a) Green ceramic
b) 550C burnout dwell
c) 850C firing (note shrinkage)



FAMEs (Fatty Acid Methyl Esters)

Cell Membranes

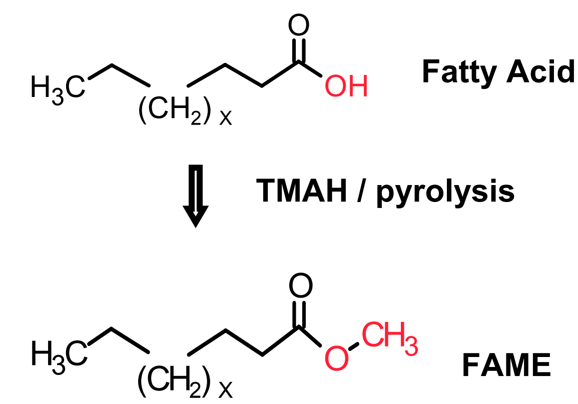


Bacterium

Cell membrane - lipid bilayer with proteins

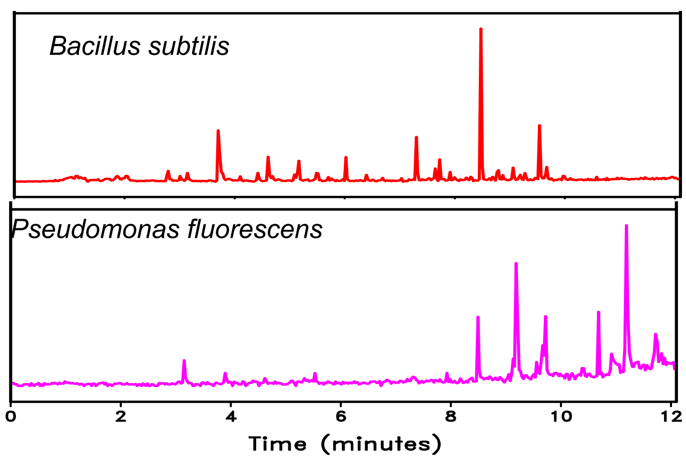
A common membrane phospholipid, a diglyceride

A fatty acid



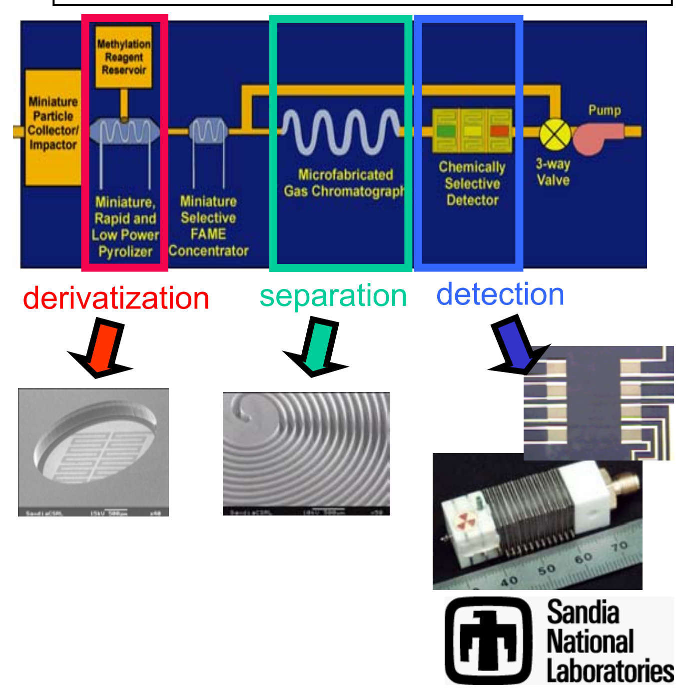
Spore

Bacillus spores also contain dipicolinic acid which can act as biomarker



Micropyrolysis/methylation Produces FAMEs from Whole Cells

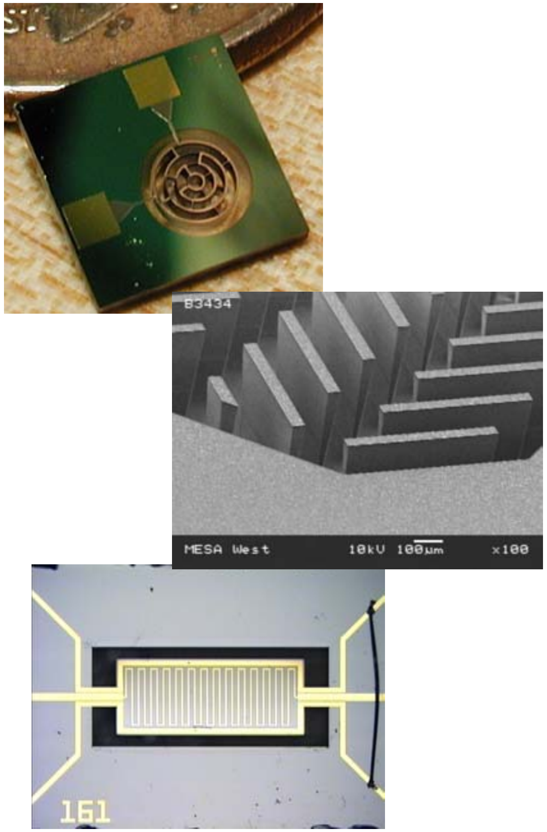
(Commercial GC/MS analysis of micropyrolysis products)



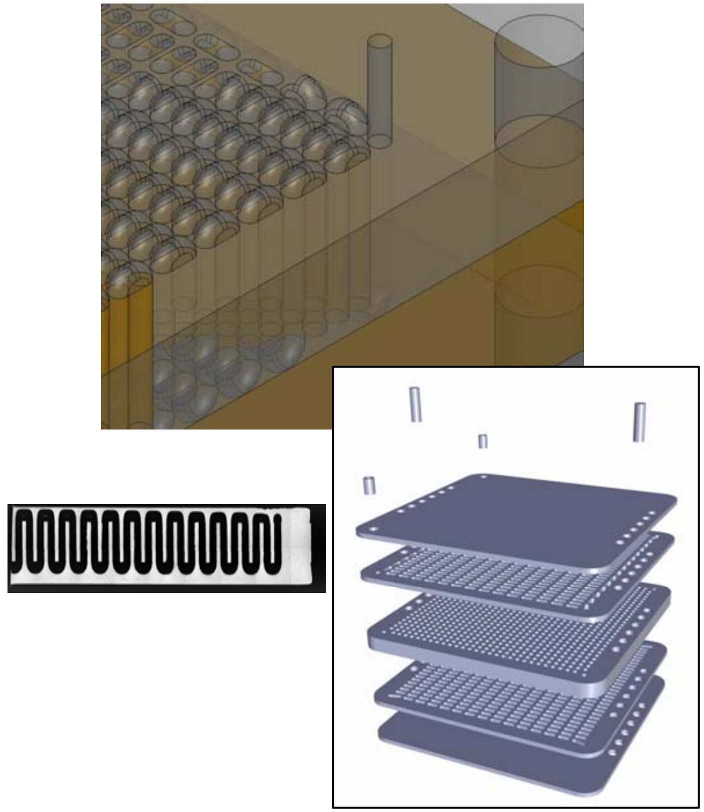
1764 Contact: Curt Mowry

Next-Generation Systems

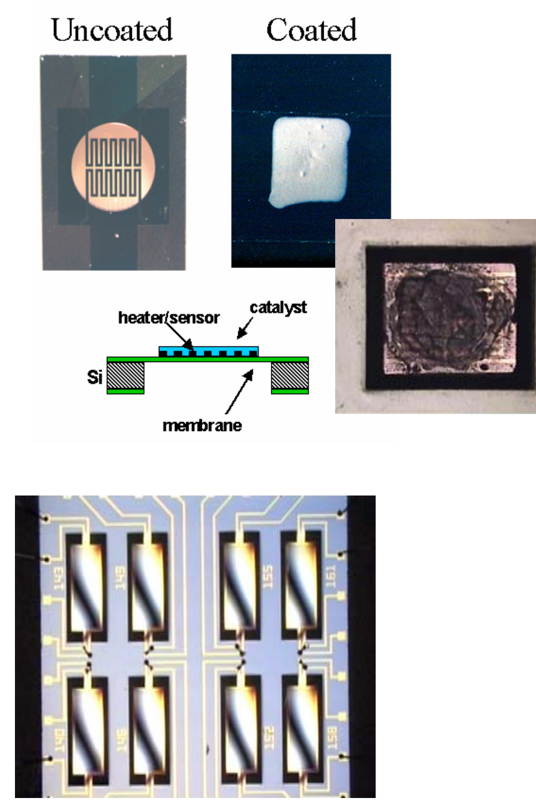
Preconcentration



Separation



Detection



- Higher volume sampling for rapid, lower minimum detection levels → miosis levels.
- Improved components for wider dynamic range analyses & lower false positives.
- New components for broad-spectrum analysis: CWAs, TICs, VOCs, NTAs, explosives, etc.
- Multichannel systems for broad-spectrum analysis in a single unit.

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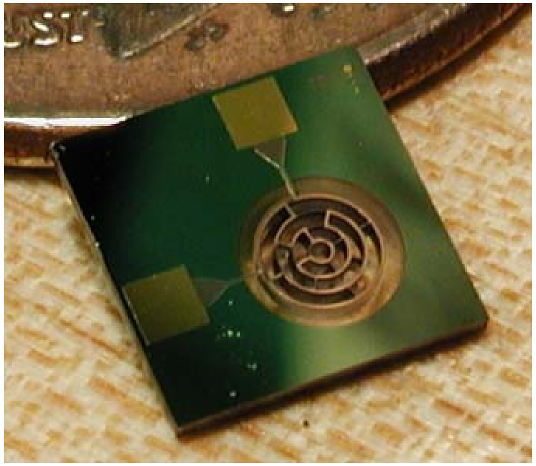
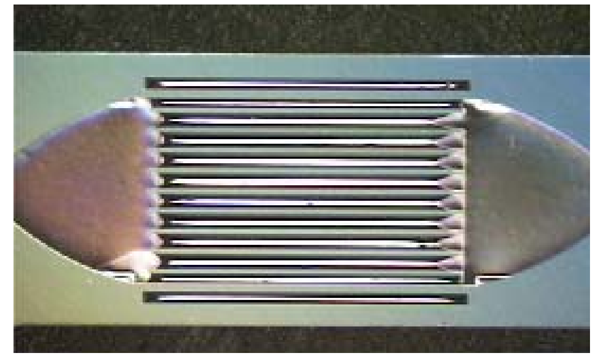
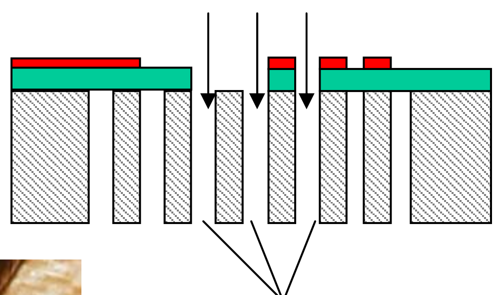
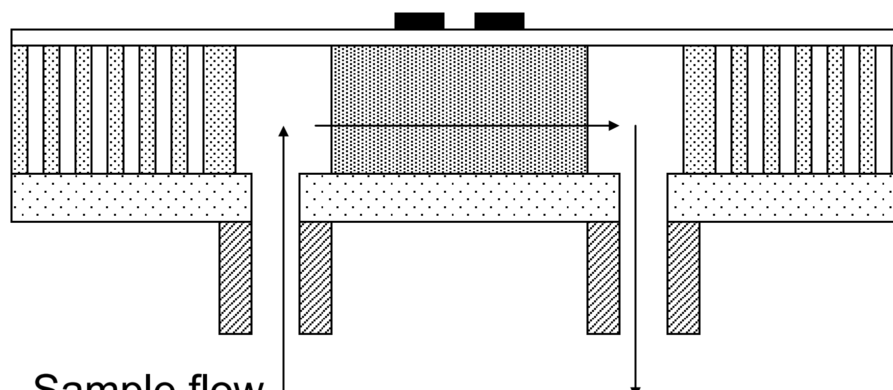
3DPCs: Increased Collection and Improved Gas Flow



New preconcentrator platform uses the same materials for selective preconcentration but enhances uptake and capacity.







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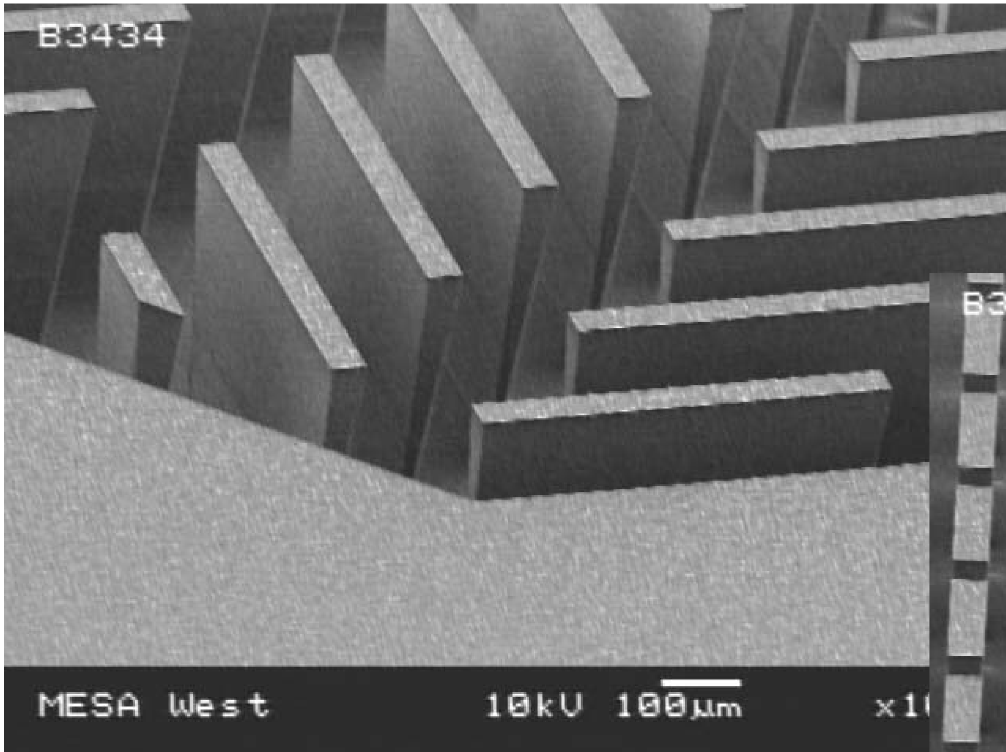
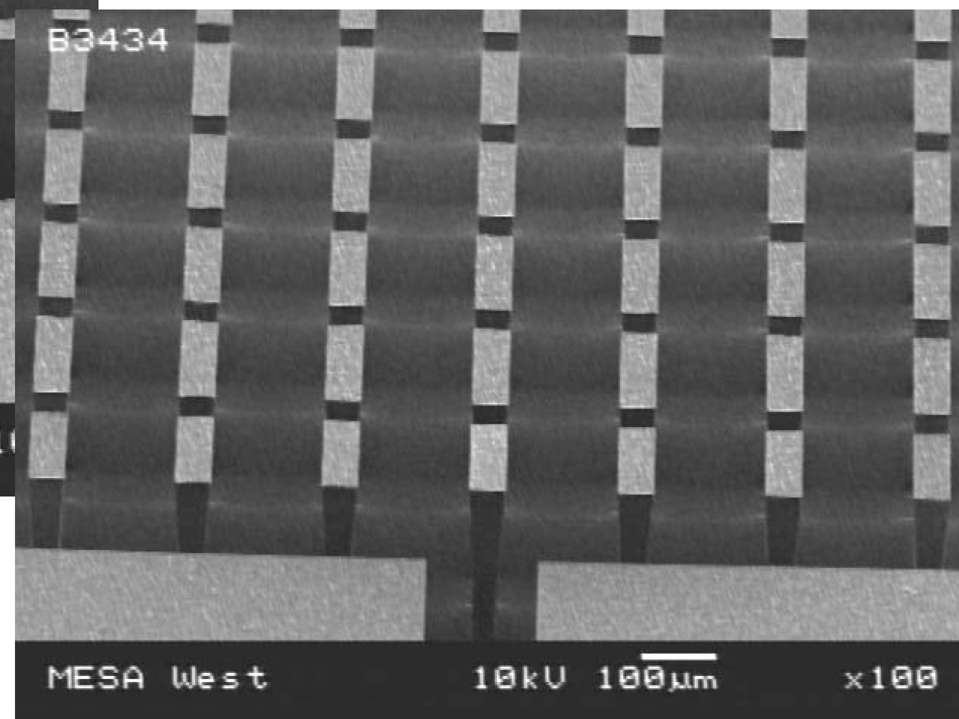
Highly Tortuous Path Preconcentrator

For Enhanced Collection of Volatile TICs





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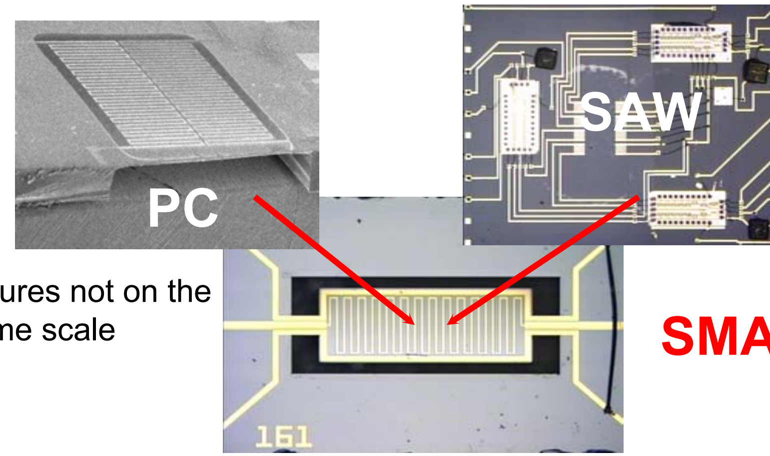
Smart PC™ combines preconcentration and detection to accelerate and automate detection

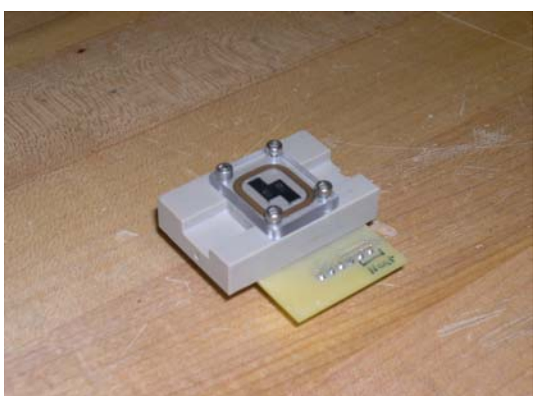
- DOD: reduced analysis times with increasing target concentration
- MEMS resonator with a heater/adsorbent weighs the sample & decides when it has collected enough
- Modular fixtures
- Circuit autotunes, autozeros
- Software subtract reference and smooth

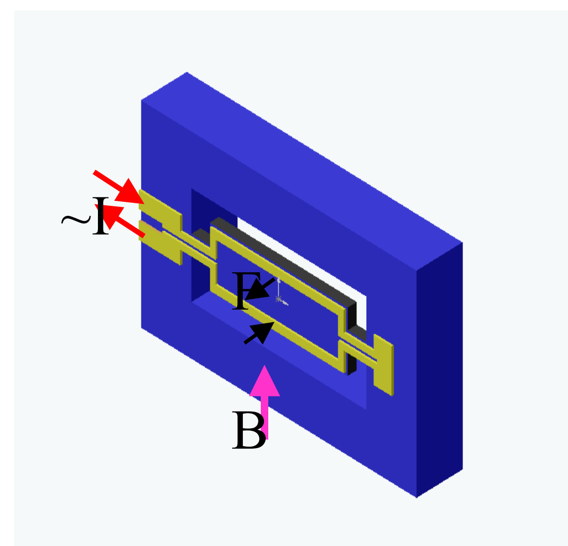


Figures not on the same scale

SMART PC™

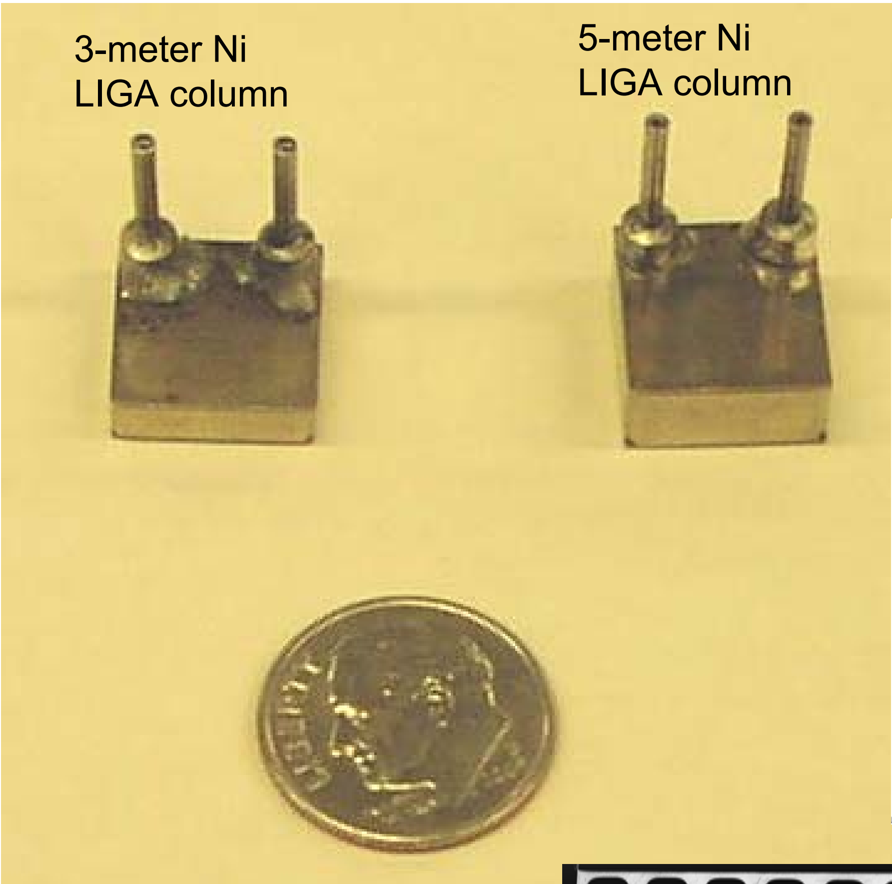
Reduced need for trained operators



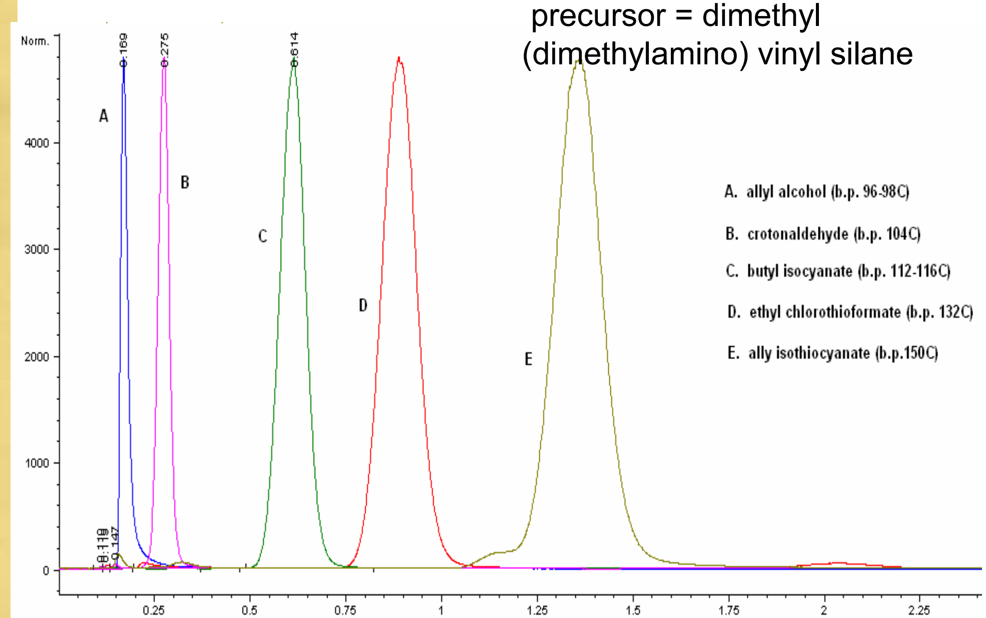


National Laboratories

Ni LIGA Columns



Oven 40C
N2 carrier @ 2.1 sccm
2 meter silicon based column
phase = polydimethylsiloxane
precursor = dimethyl
(dimethylamino) vinyl silane



X-section micrograph – 1 row

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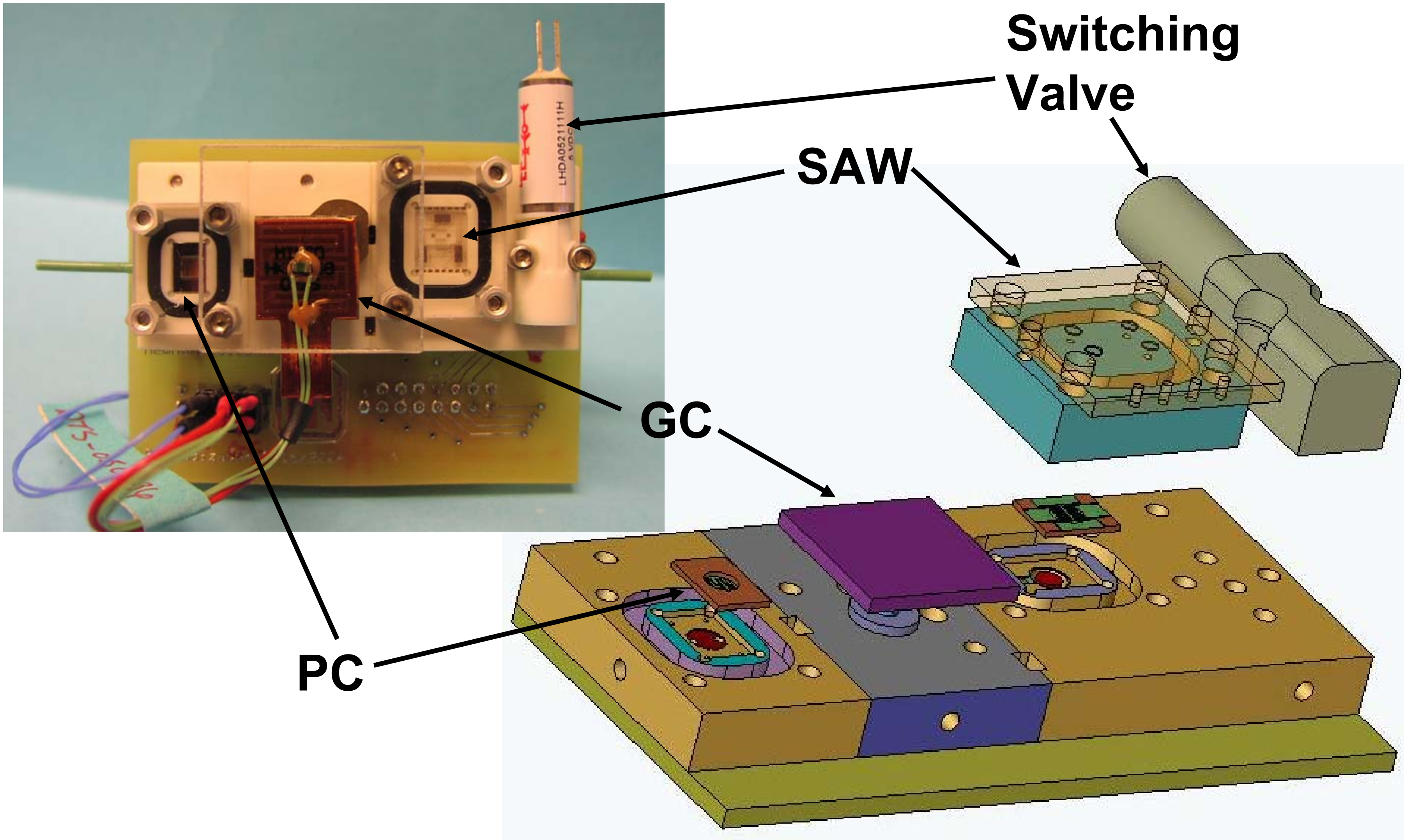
Modular Gas Manifold for Component Assembly



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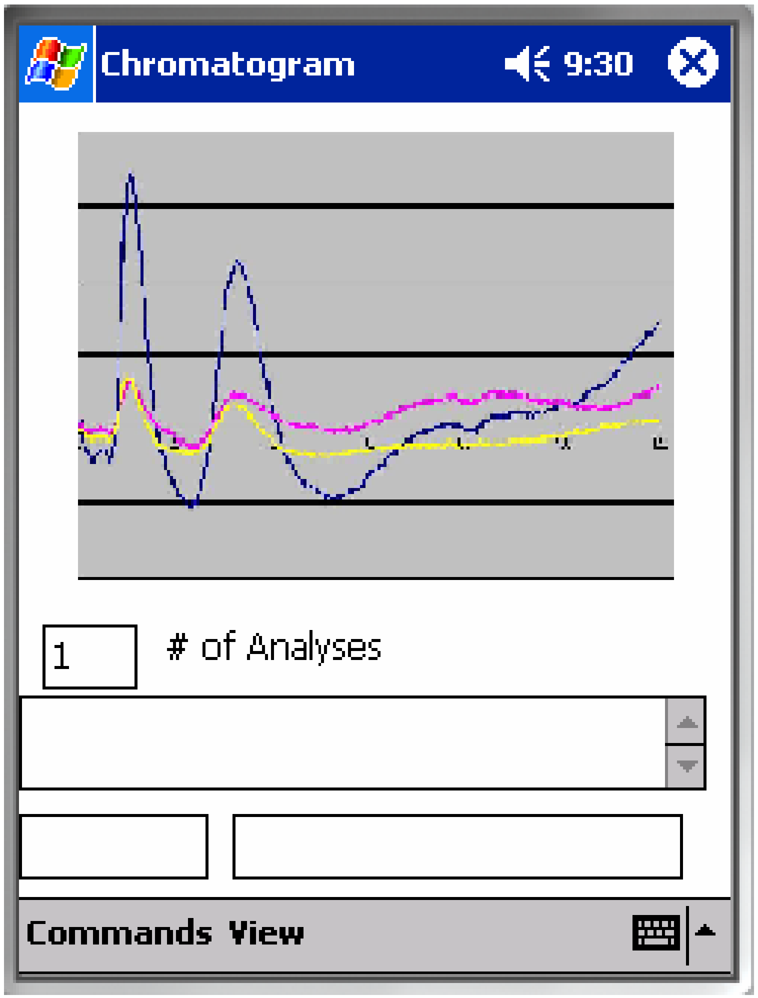
PDA-Based Handheld Unit



N^{th}-Generation Micro-Gas Analyzer

Sandia National Laboratories

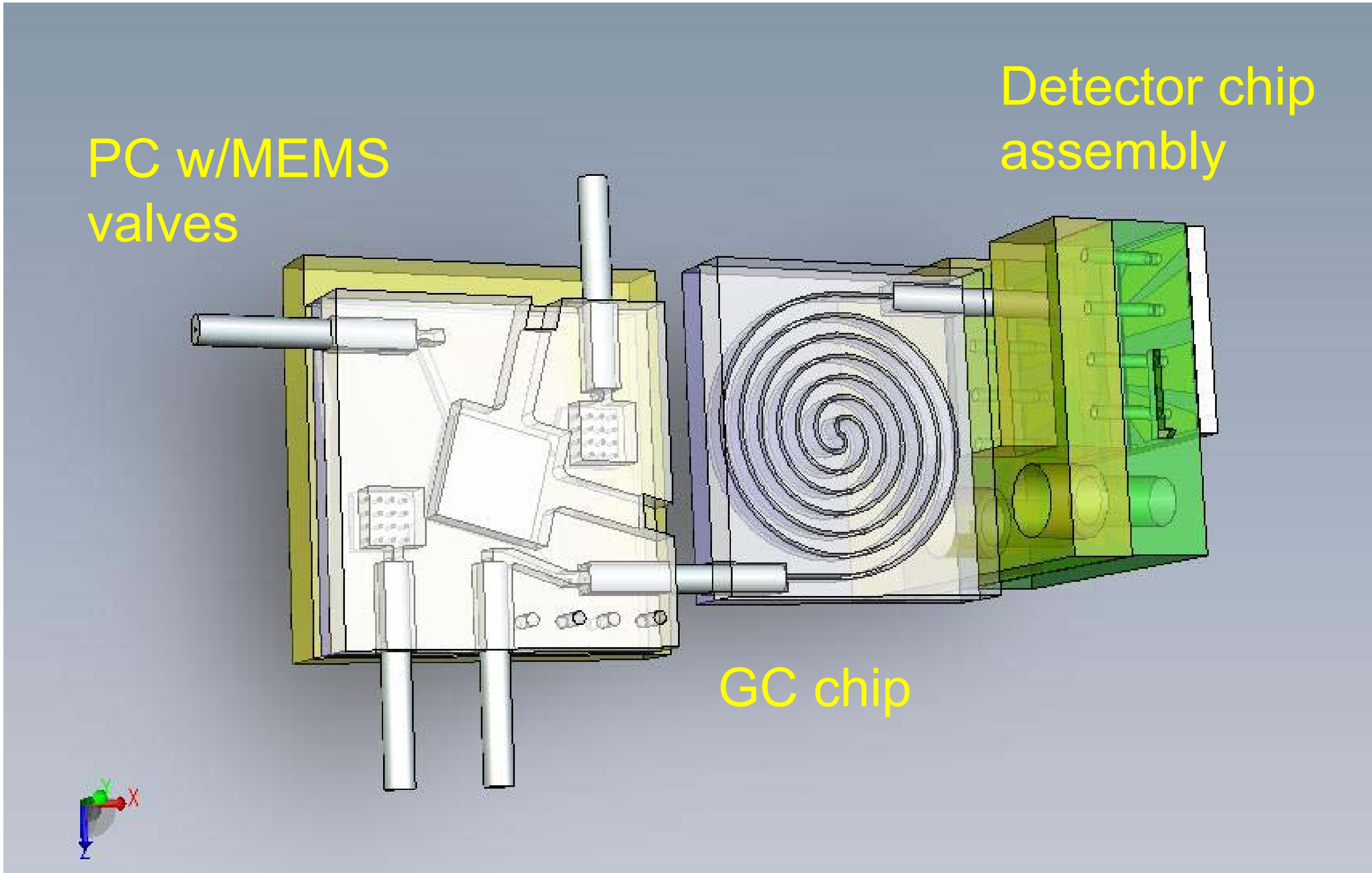
Micro Gas Analyzers Program: *Fast* GC separations

Program goals:

- Size < 2 cm^3
- 20/10 Separation < 4 sec
- Peak Capacity > 40 x 30
- Detection Limit < 1 ppt
- Energy/Analysis < 0.5 J
- FAR < 1 in 10^7 for 20/10 mix (block ROC)

Sandia National Laboratories

MGA System
Microfabricated Components



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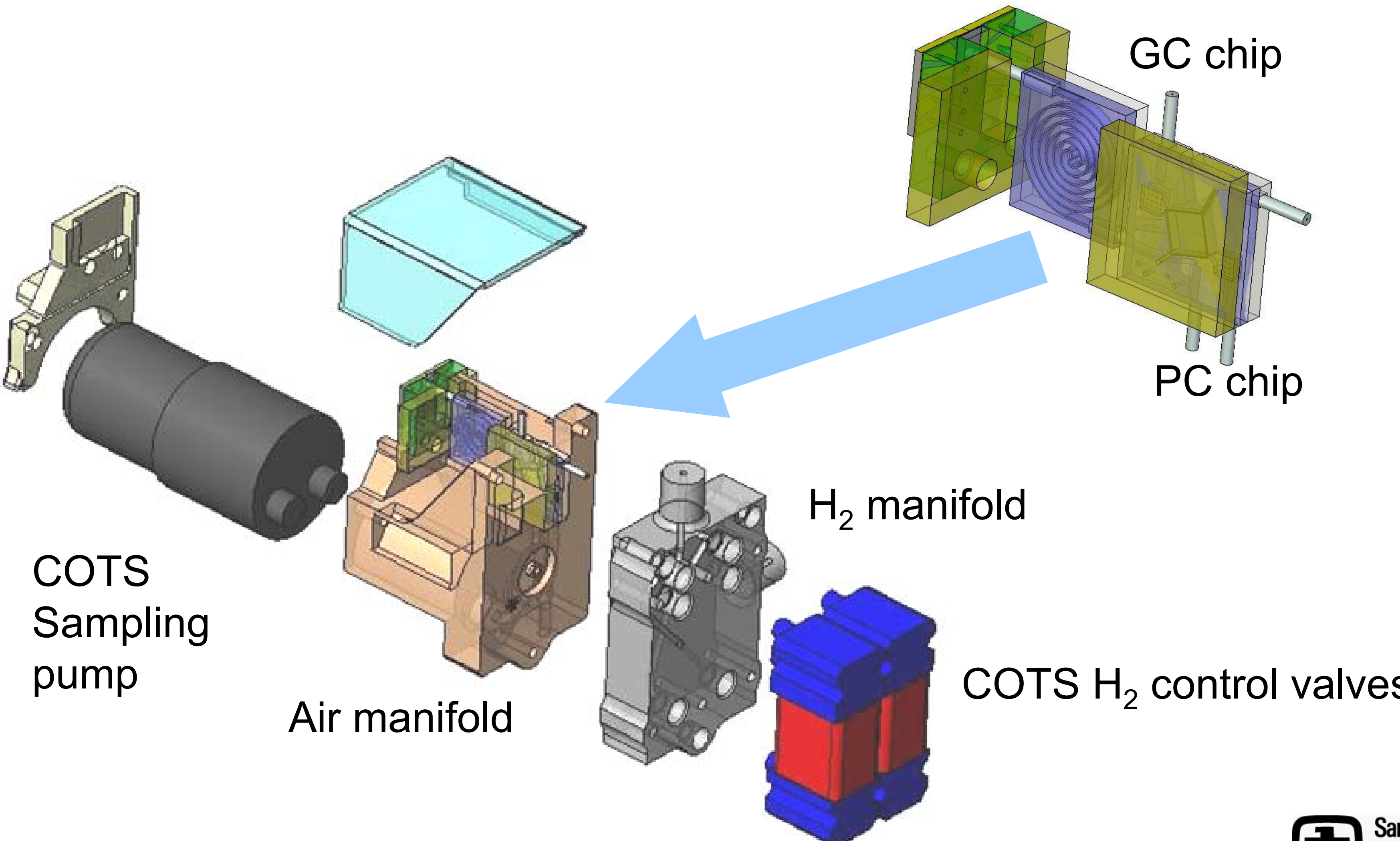
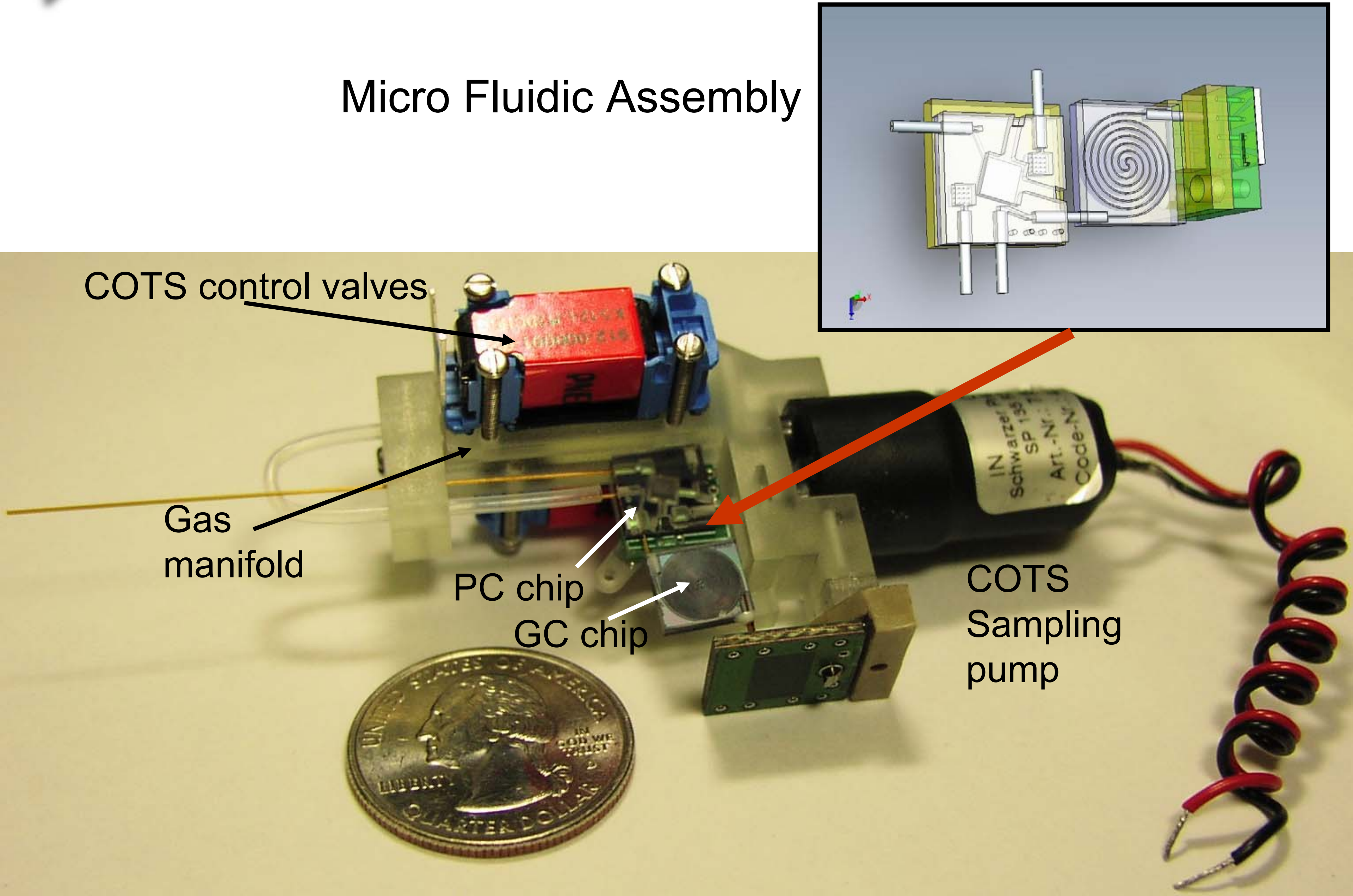
MGA System



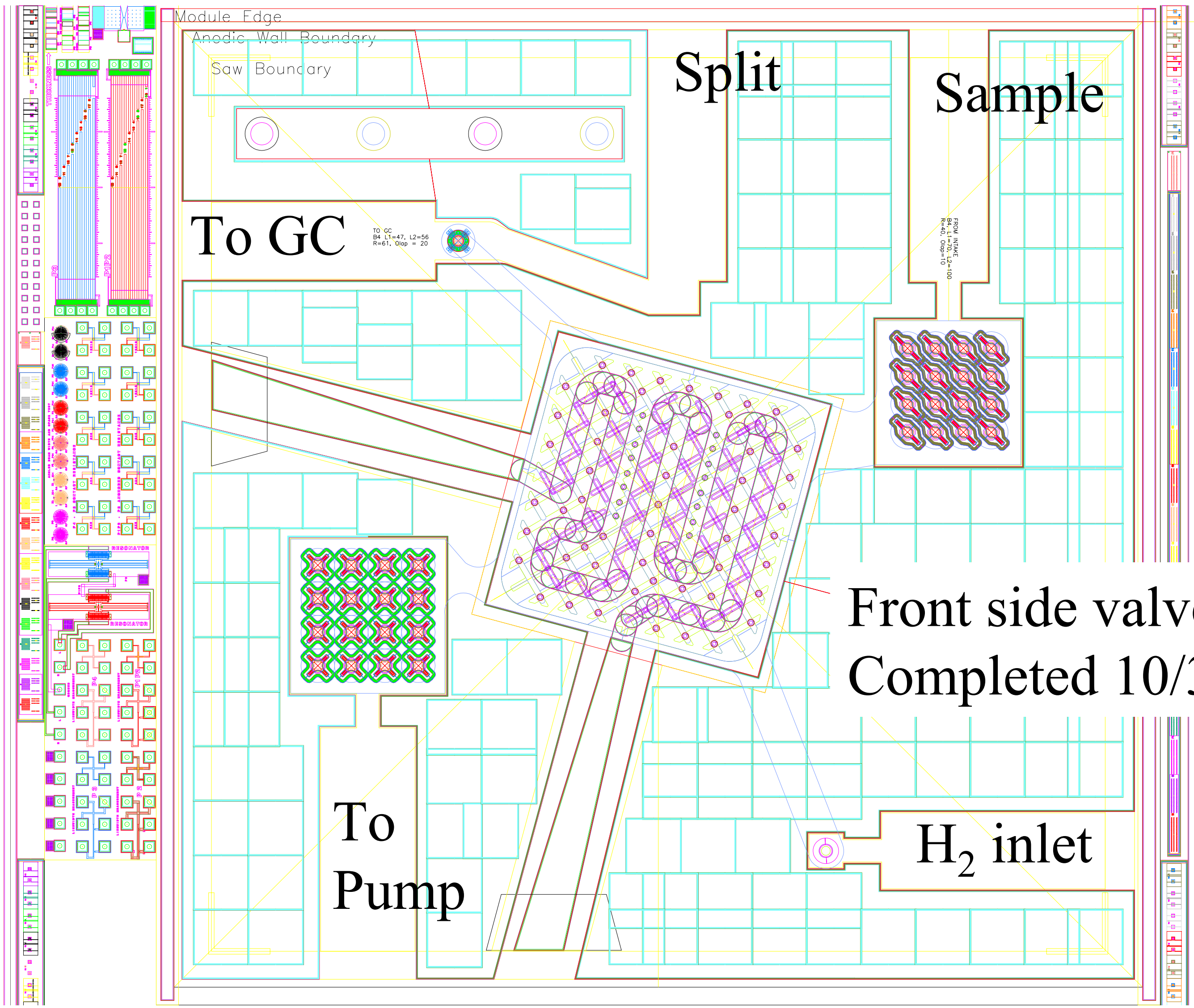
Sandia National Laboratories

Total Fluidic System Assembly

Micro Fluidic Assembly



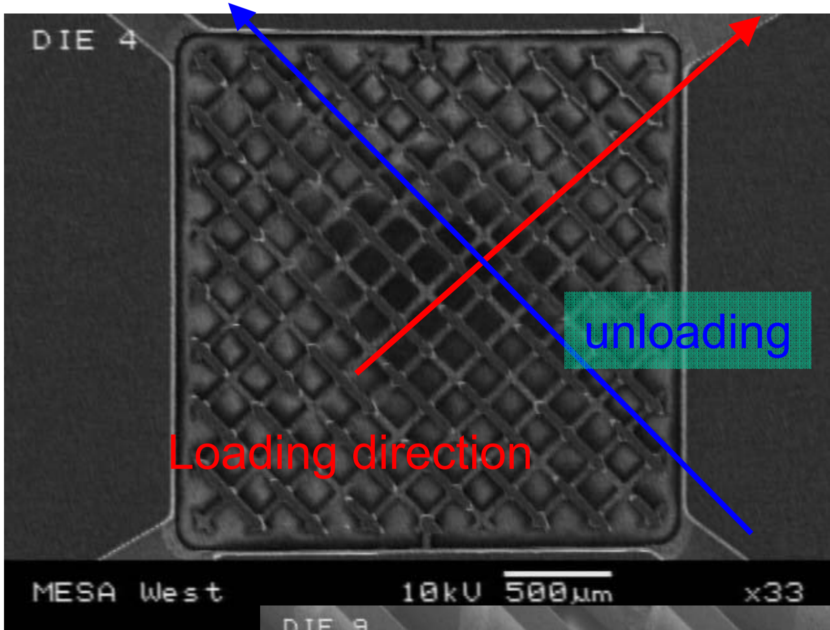
PC/Valve Chip MDL Processing

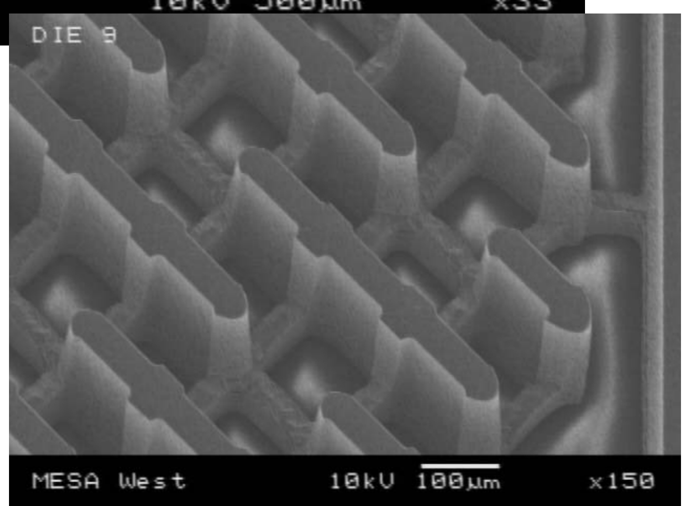


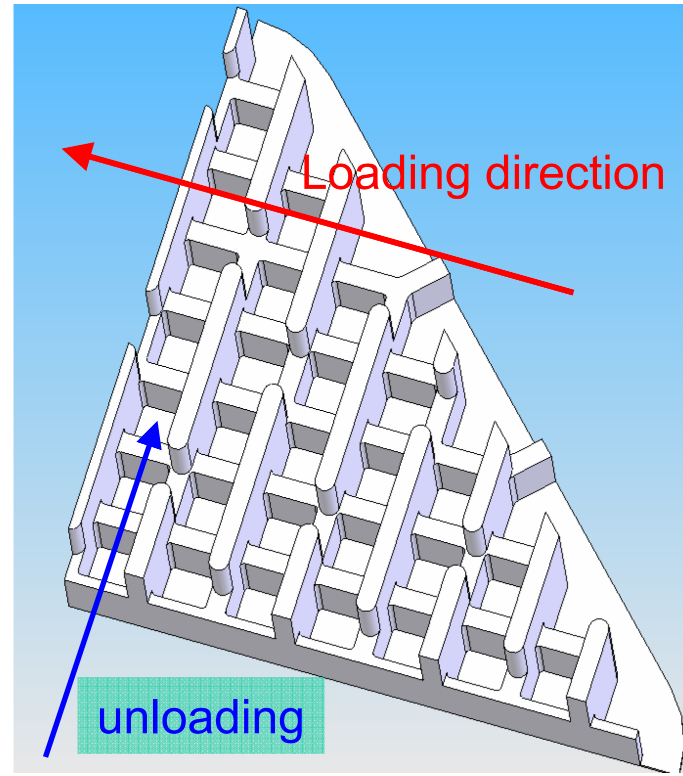
8 x 8 mm

Front side valve structures
Completed 10/31/06

MGA Preconcentrator Design







2 layer photolithography is used to create partial height struts/support and full height adsorbent fins

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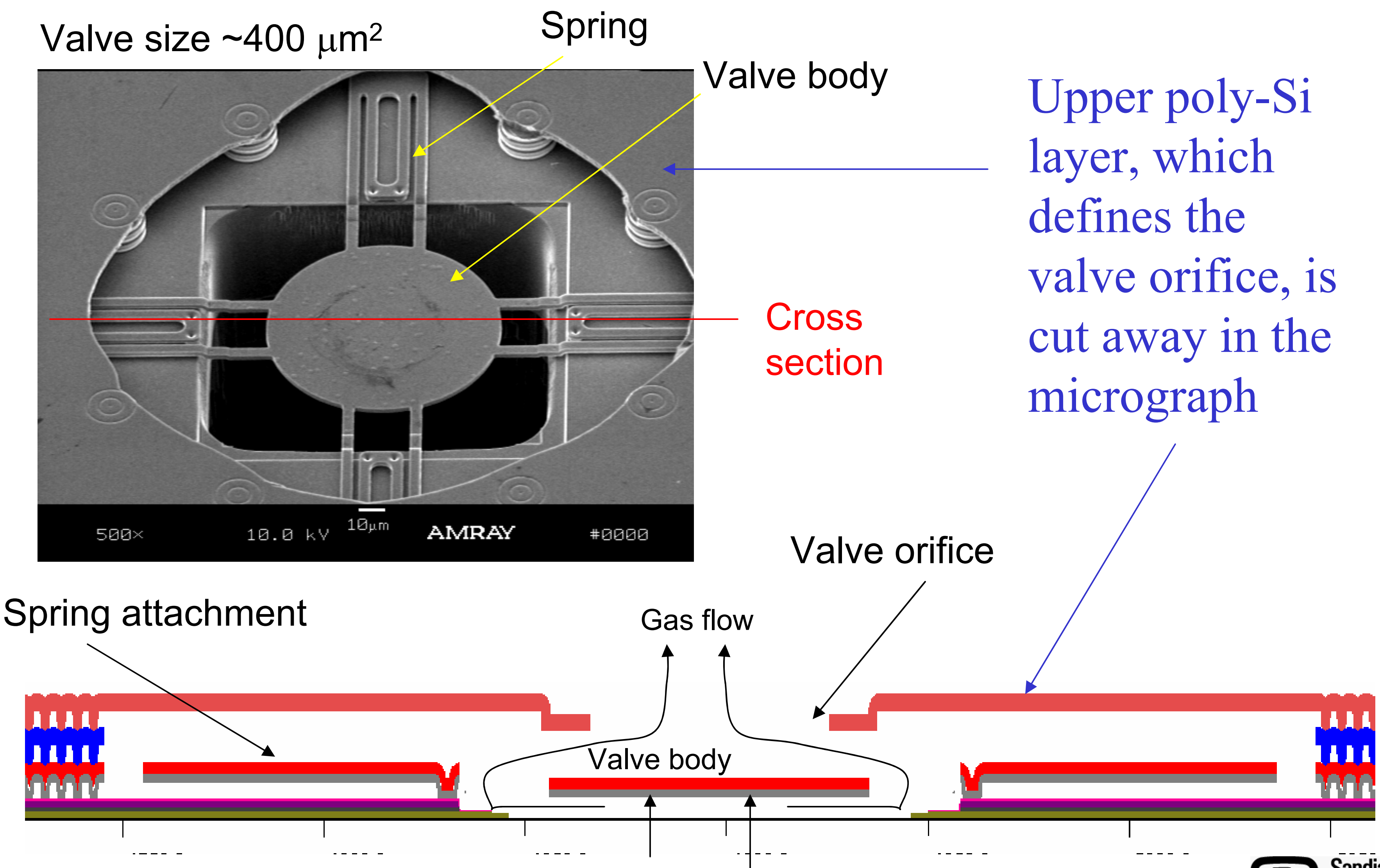
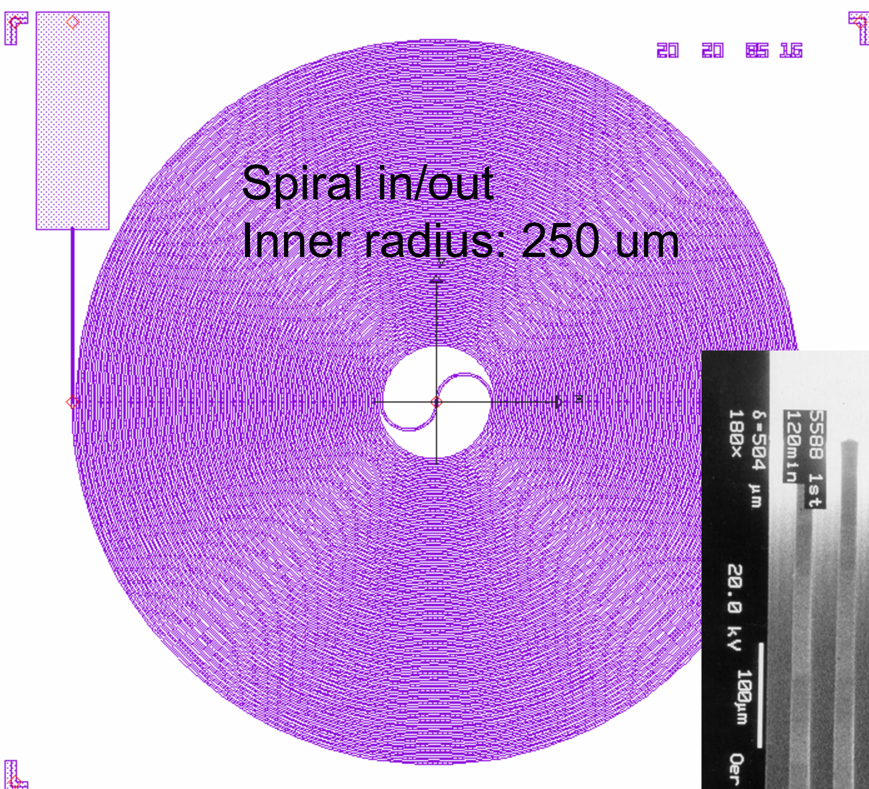
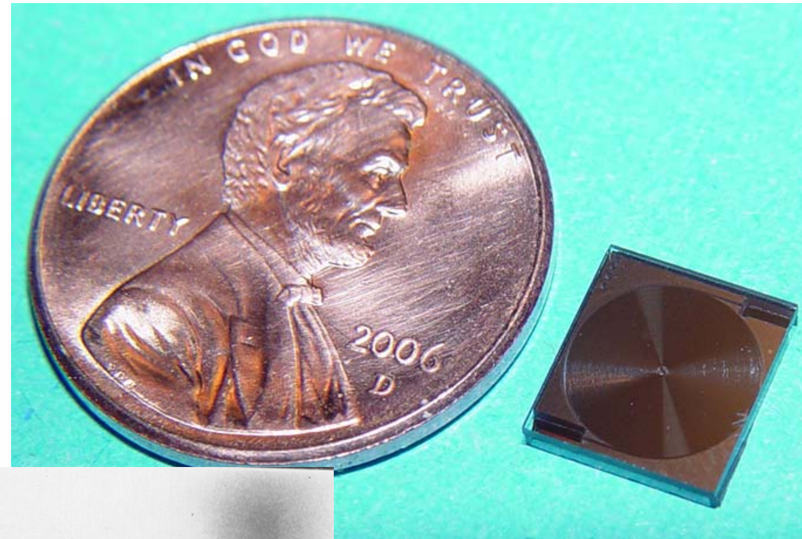
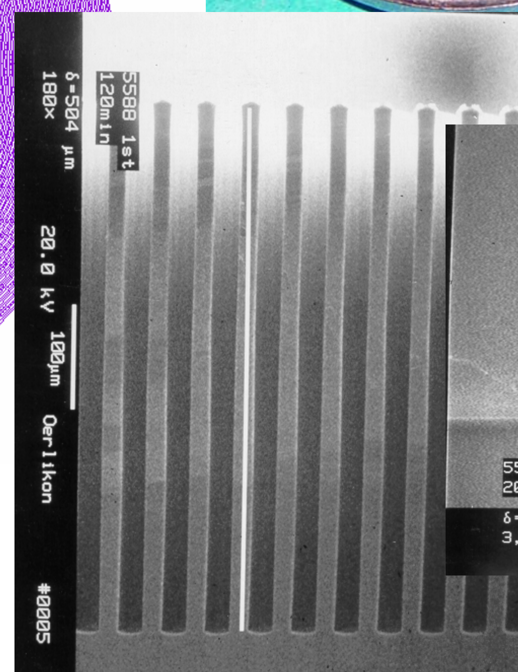
Valve 2 - SUMMiT™ design and fabrication

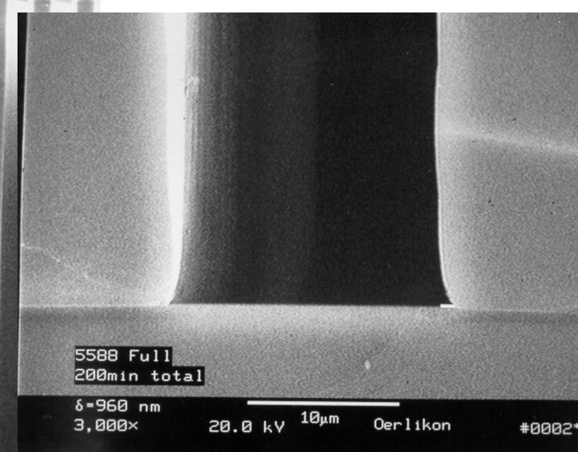


Sample Closeup: Die 1 fabricated on 20 um SOI (1 um BOX, 650 um Si)







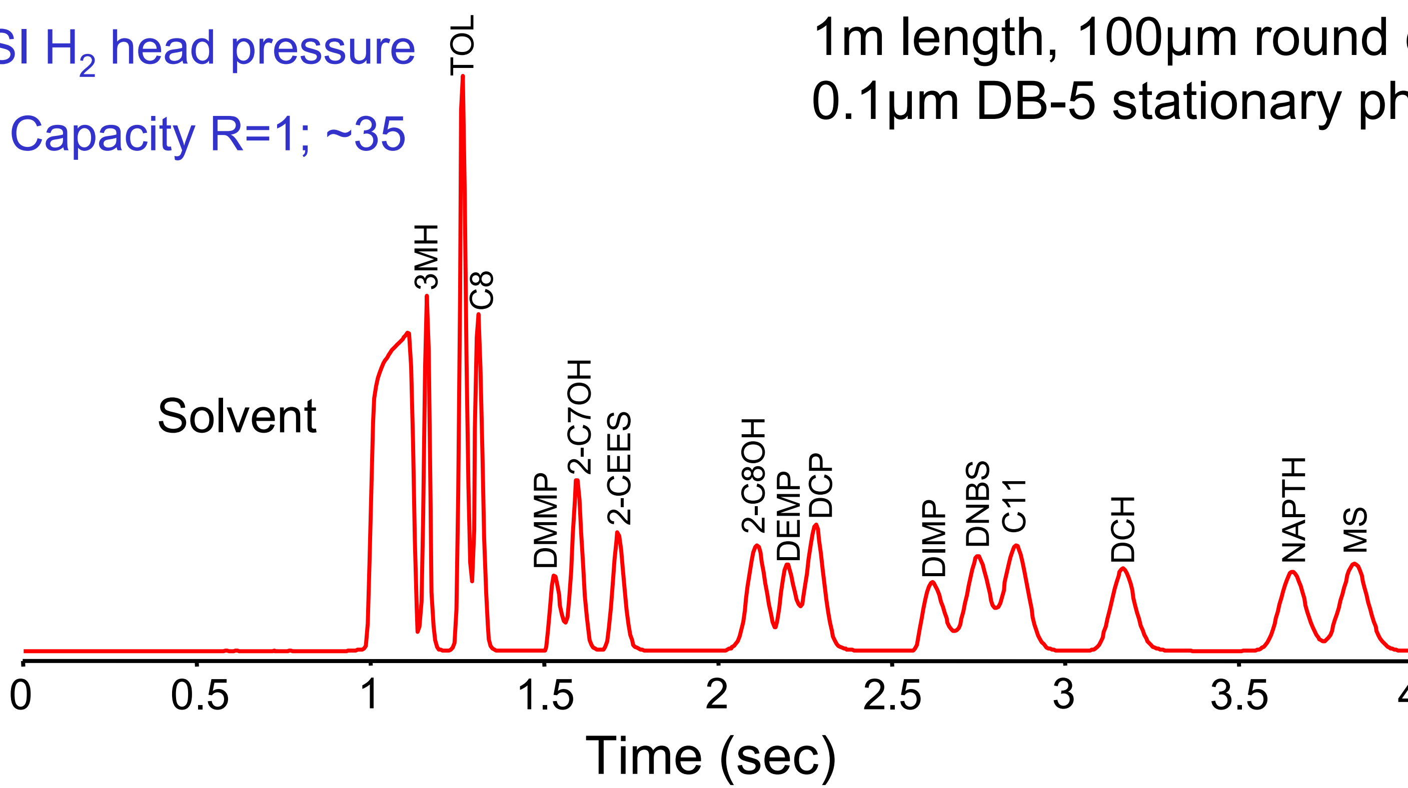


Delay layer has arrived and is awaiting processing

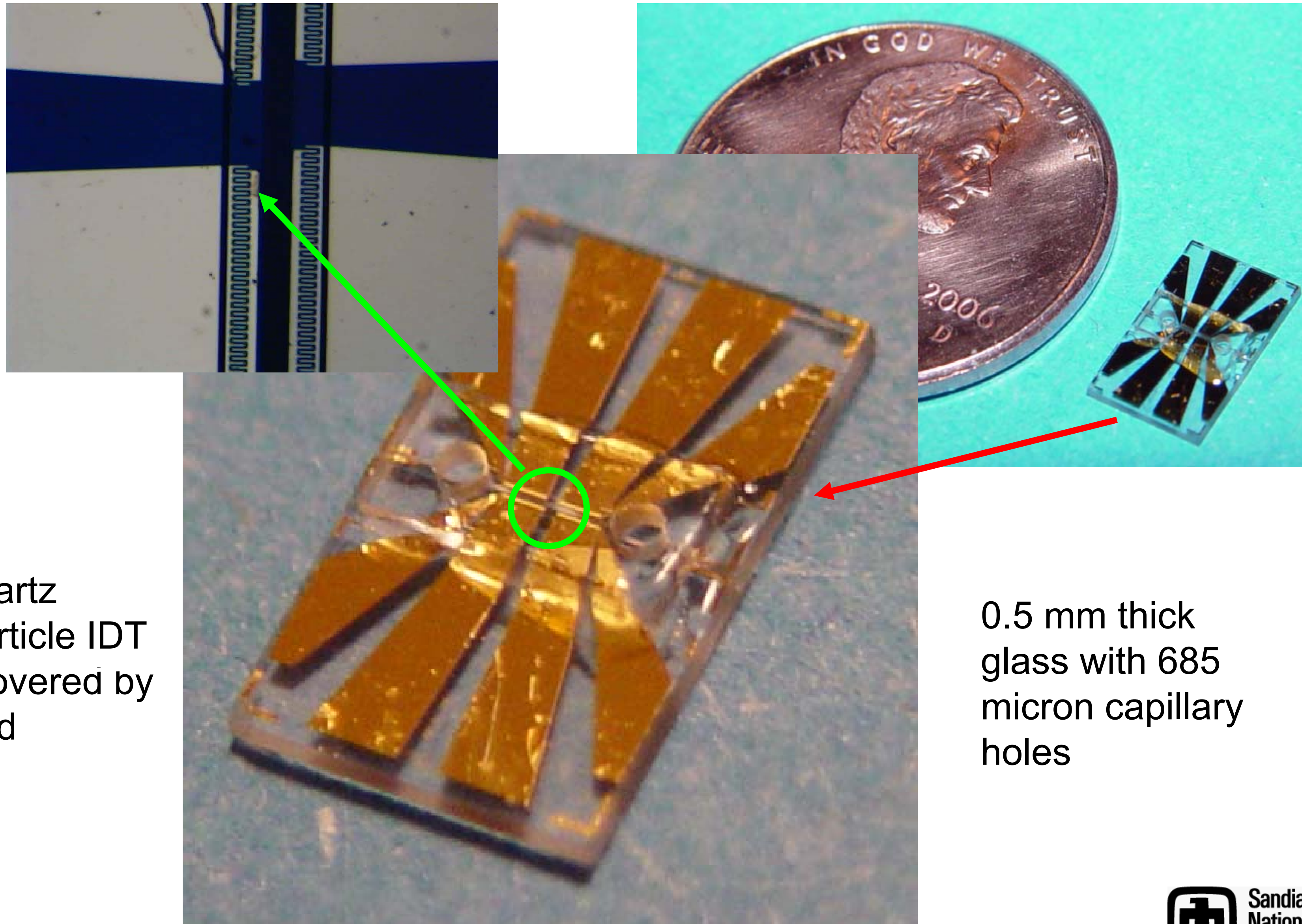
Separation of 16 Compounds in < 4 sec

- Temperature Programmed from 59 to 87 °C
- 30 PSI H_2 head pressure
- Peak Capacity R=1; ~35

8 CWA simulants
8 interferents
1m length, 100μm round column
0.1μm DB-5 stationary phase



Nanoparticle IDT Arrays



Two quartz nanoparticle IDT chips covered by a flow lid

0.5 mm thick glass with 685 micron capillary holes

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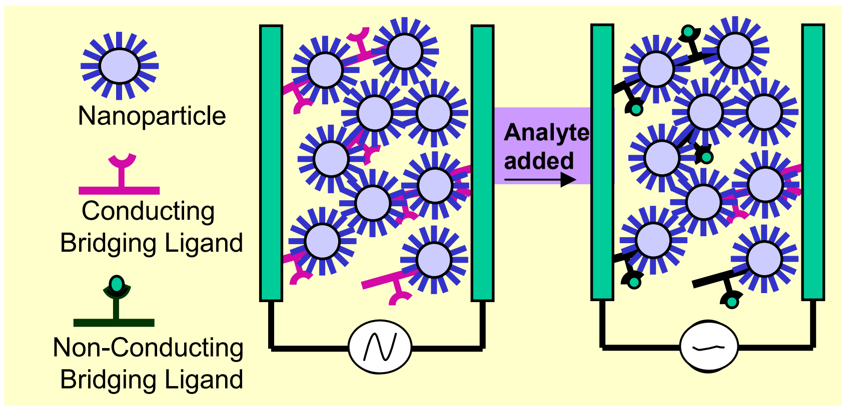
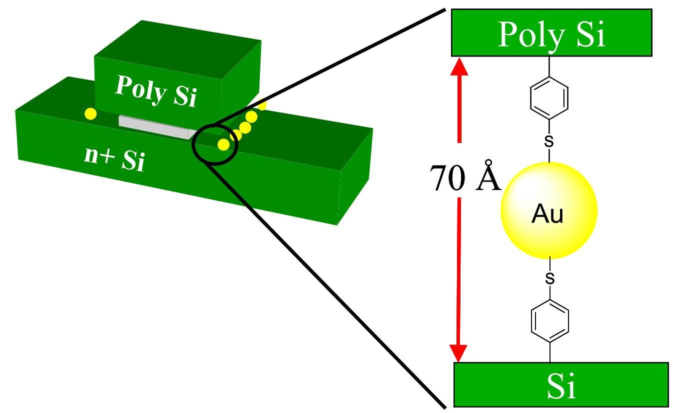
Nanoparticle-Based Detectors

Analyte-Ligand Interactions

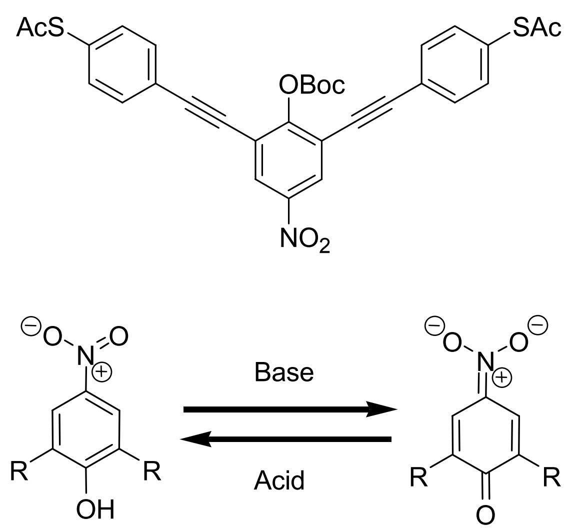
- Sterics
- Electronics
- Geometry



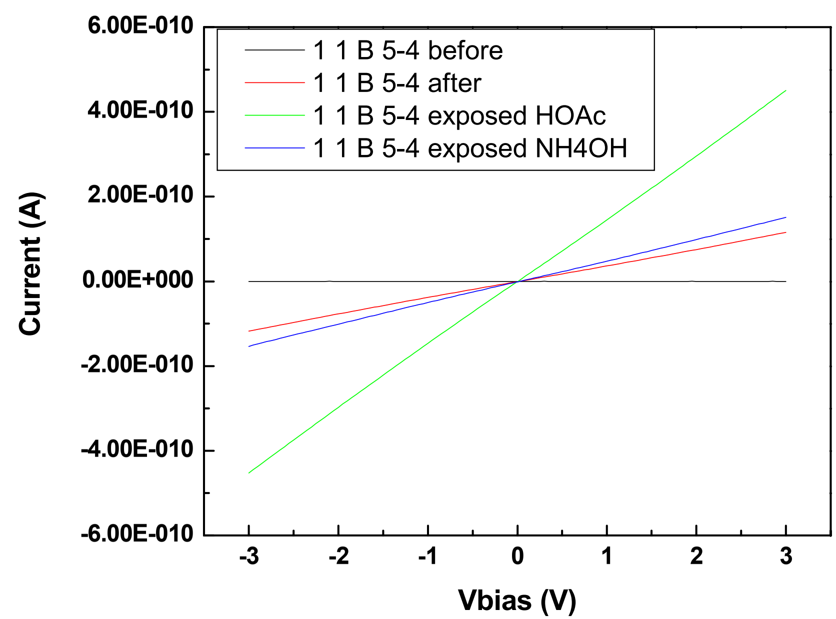
nanogap junctions



Au nanoparticle film crosslinked with nitrophenol phenylene ethynylene



Conjugated **Cross Conjugated**



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Micro-Calibrator Chips

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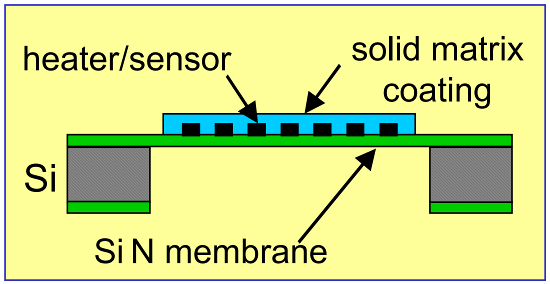
Micro-Calibrator Development

Microfabricate an internal source that enables calibration of microGC-detection systems with known and highly-repeatable retention time and gas concentration

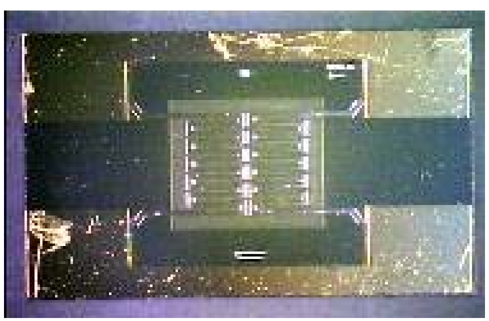


Tetra-alkyl ammonium Salts:

- Thermally labile
- 2 retention peaks
- Water soluble solutions
- Useful chromatographic retention
- Good mass response (for at least 1)

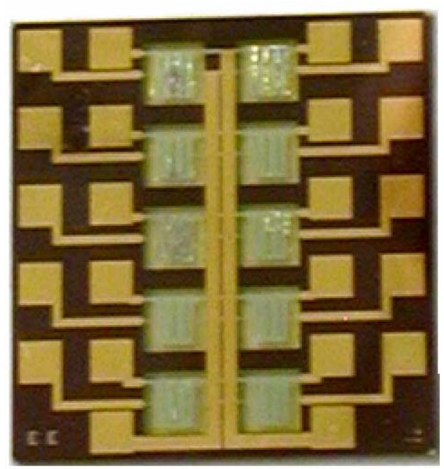
$$[N(C_3H_7)_4]^+[OH]^- \xrightarrow{\text{heat}} N(C_3H_7)_3 + C_3H_6 + H_2O$$

tetrapropyl ammonium hydroxide → tripropyl amine + propene + water

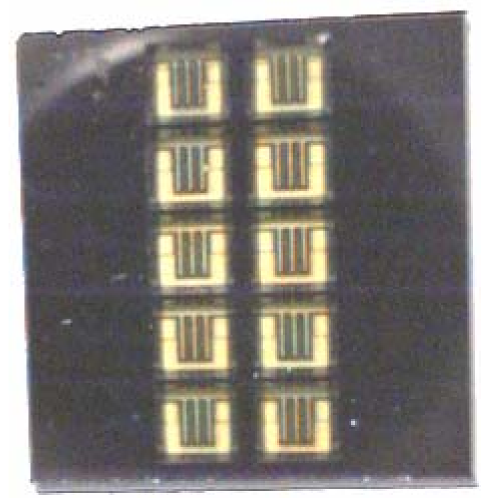


single μhotplate device

10 x



array of 10 thermally actuated μhotplates



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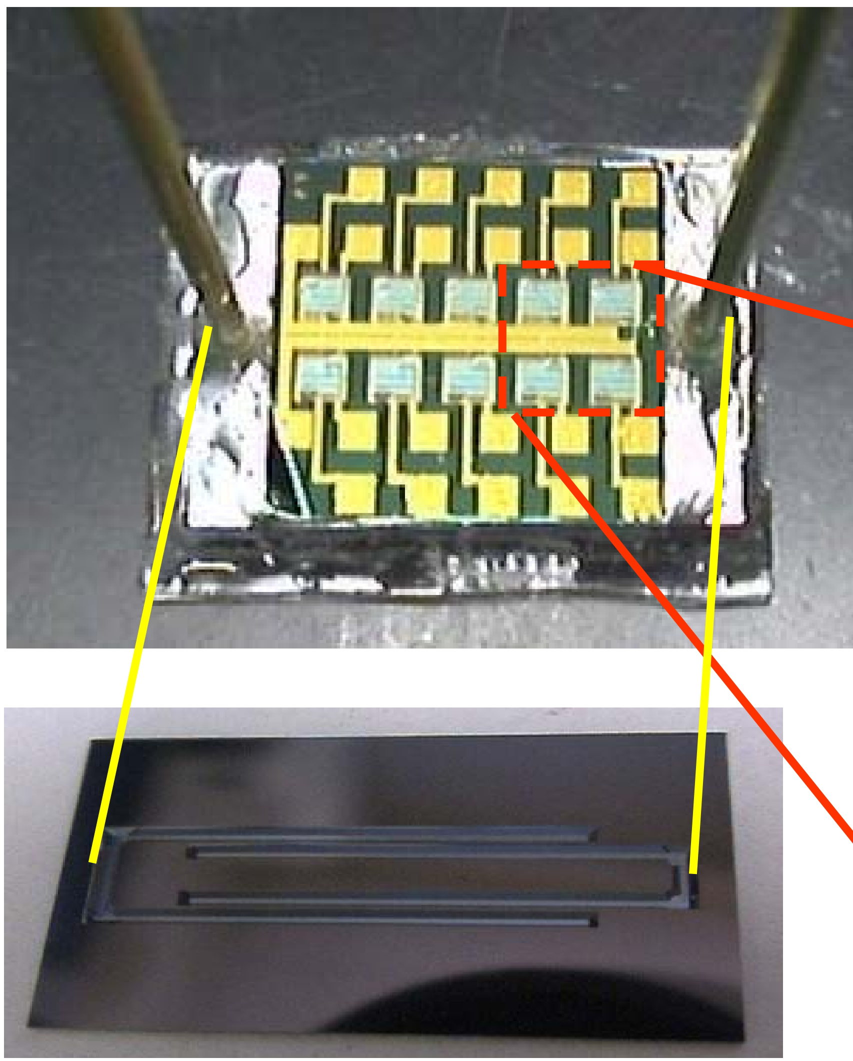
Micro-Calibration Chip

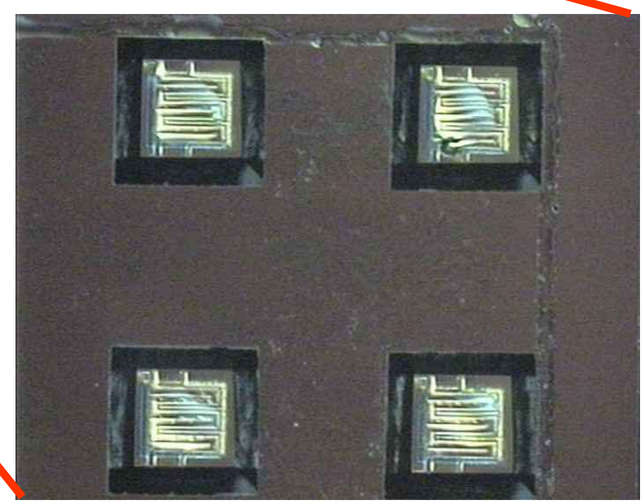
tetrapropyl ammonium hydroxide

$$[N(C_3H_7)_4]^+ [OH]^-$$

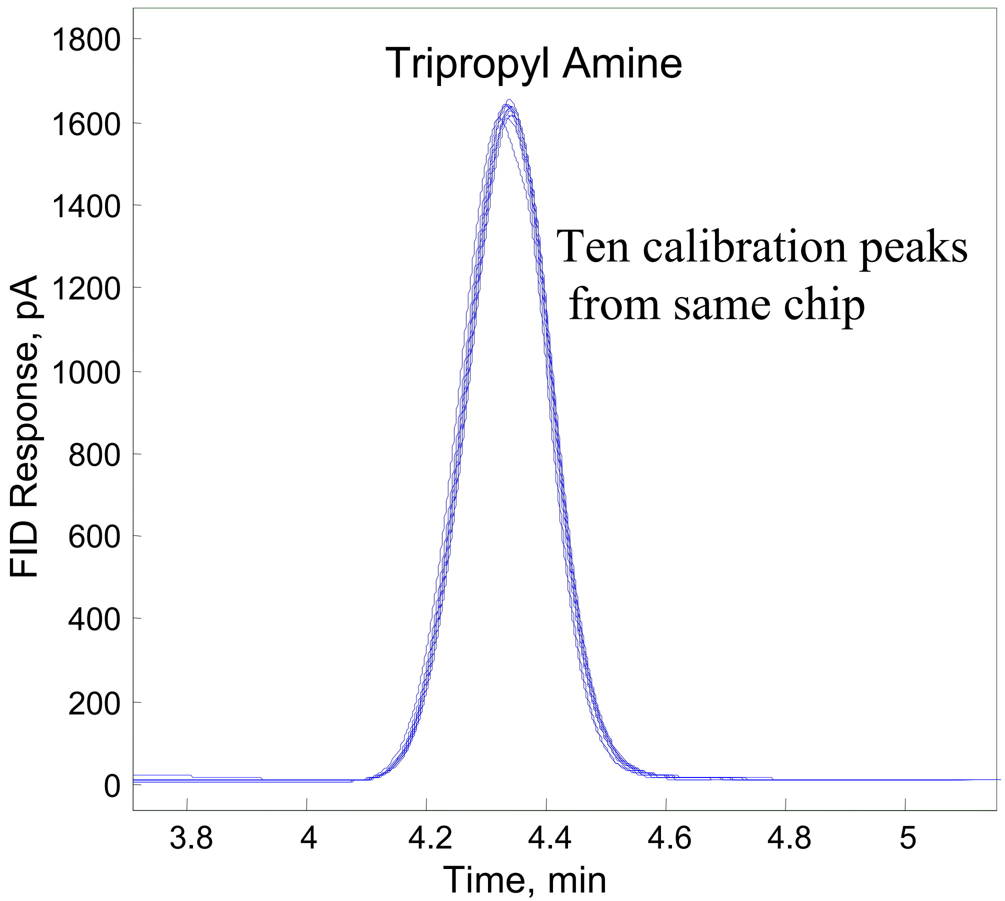
tripropyl amine + propene + water

$$N(C_3H_7)_3 + C_3H_6 + H_2O$$





Micro-Calibration Chip



Fluidic fixturing pieces were HMDS treated prior to fixture assembly. Air carrier at 7 p.s.i., flow rate 11 ccm, oven 60C, 15-m DB-1 megabore column, FID.

Reproducibility (one chip)

- Mass flux: 0.5%
- Peak height: 1.0%
- Peak Width: 1.3%
- Retention Time: 0.14%

Reproducibility (between chips)

- Mass flux: 5%
- Peak height: 5.5%
- Peak Width: 0.06%
- Retention Time: 0.8%

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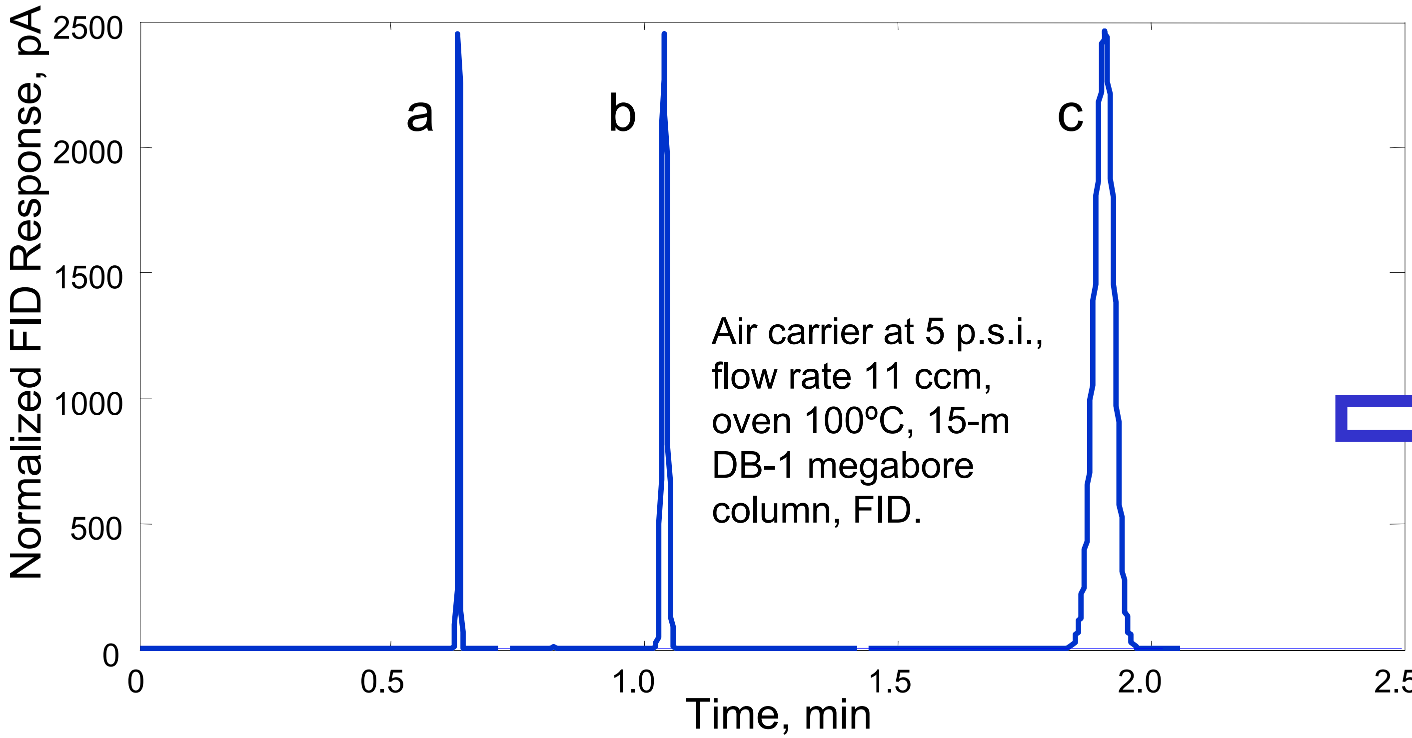
Calibration Markers – Match to Task



(a) cleaved alkene
(b) triethylamine
(c) Tripropylamine

(d) tributylamine at 7.8 min

Compound	Retention Time
n-alkenes	0.63 min.
triethyl amine	1.04 min.
tripropyl amine	1.91 min.
tributyl amine	7.8 min.

GC retention times of tetraalkyl ammonium hydroxide decomposition products under identical chromatographic conditions

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Micro-Hotplate Detectors

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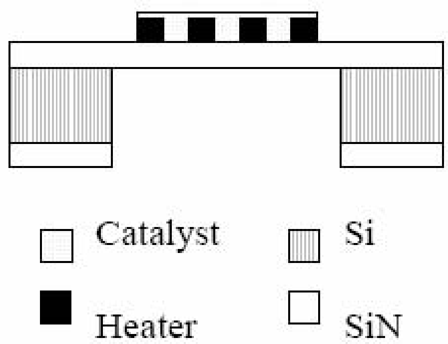
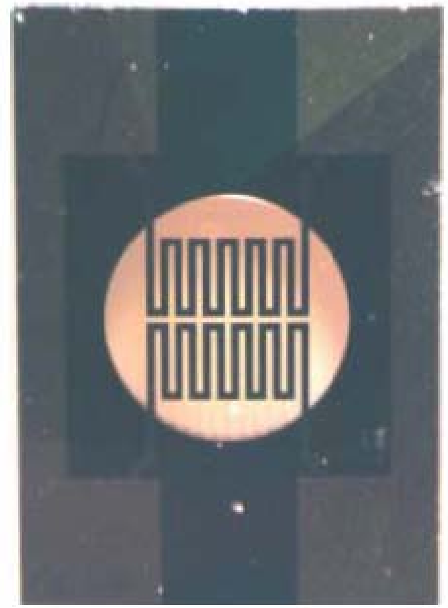
Micro-Combustor Development

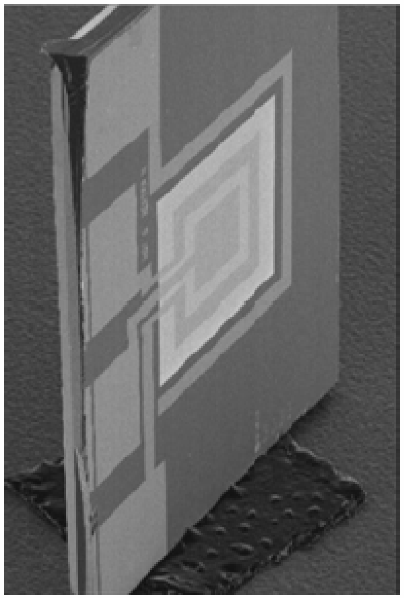


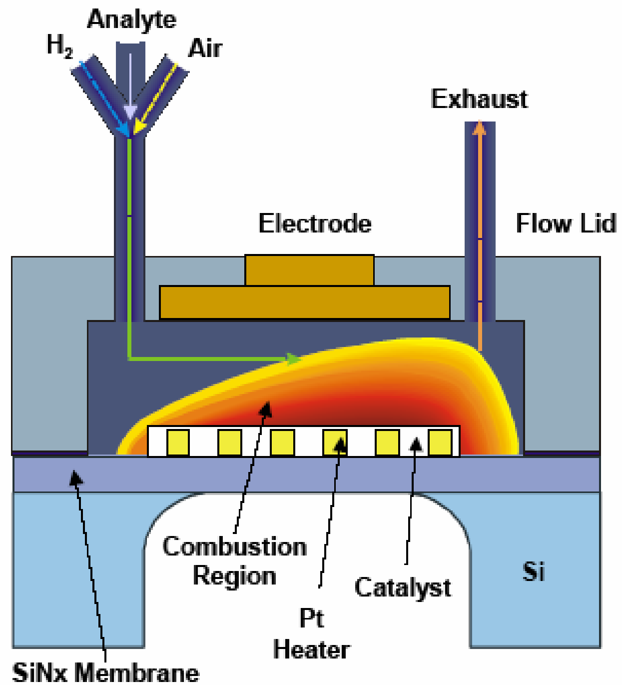


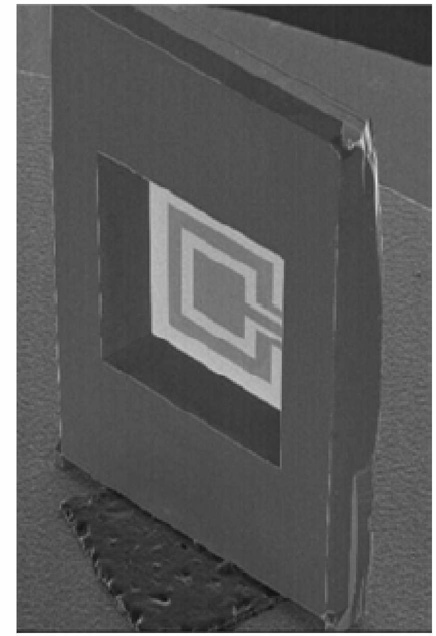
Microcombustor design and implementation.
Left: schematic cross-section of the membrane micro-hotplate.
Middle: microphotograph of the microhotplate (backlit).
Right: micropenned Pt/alumina, 25 µm thick, on the microhotplate.

Two operating modes → calorimeter & ionization detector

Micro-FID Development



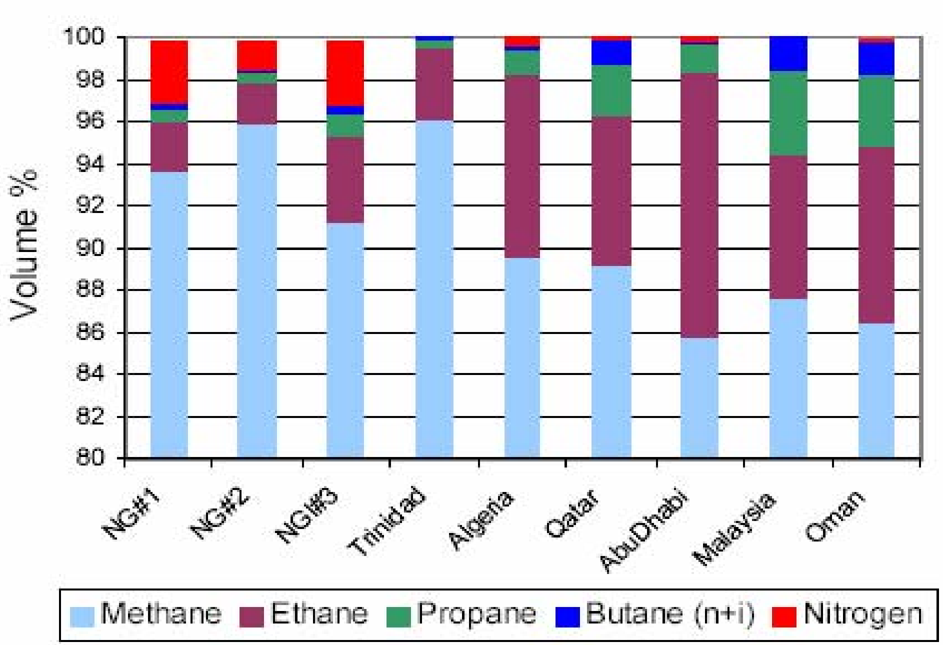




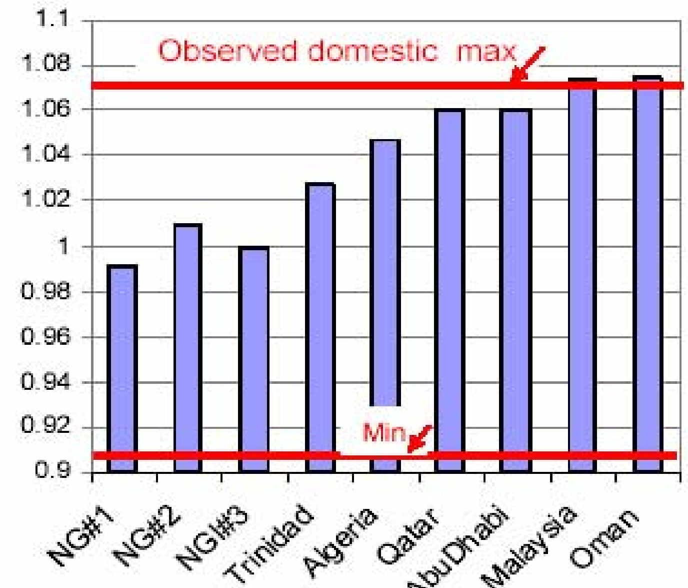
The micro-flame ionization detector (microFID).
Left: SEM of microhotplate used in microFID, front side.
Middle: cross-sectional schematic of microFID with lid.
Right: SEM of microhotplate used in microFID, etch side.

Natural Gas Composition

- Domestic Natural Gas currently has modest variability
- International LNG supply has wider composition variability
- Projections: U.S. LNG to 6.4 tcf[1] by 2025 (22 tcf 2003 total[2]).
- Domestic unconventional gas rising to 8.6 tcf by 2025.



Derived from GRI-03/0159,Gas Interchangeability Tests:Evaluating the Range of Interchangeability of VaporizedLNG and Natural Gas, Gas Technology Institute, April 2003



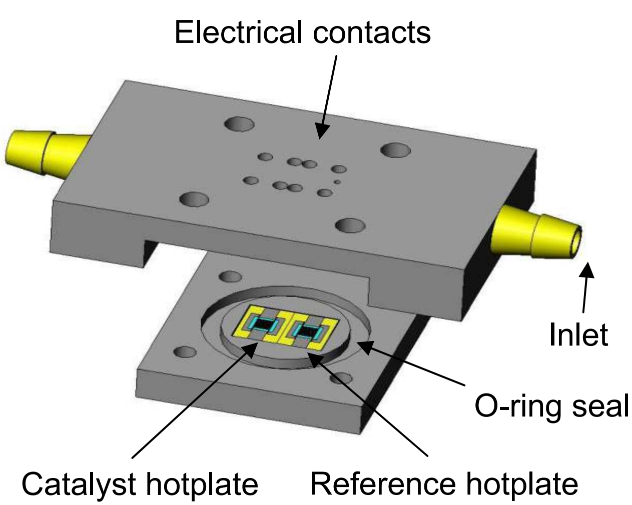
Wobbe Index HHV/(s.g.)1/2
normalized by avg #1,#2,#3 gas
(1336 btu/scf)

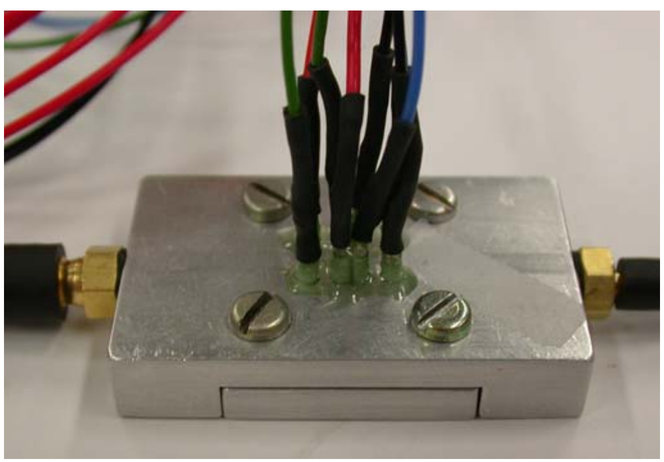
[1]. EIA Annual Energy Outlook 2005, pp. 96. [2] Ibid. pp. 95 [3] Whitepaper on Natural Gas Interchangeability, NGC+Interchangeability Work Group, Appendix A, Fig A.8

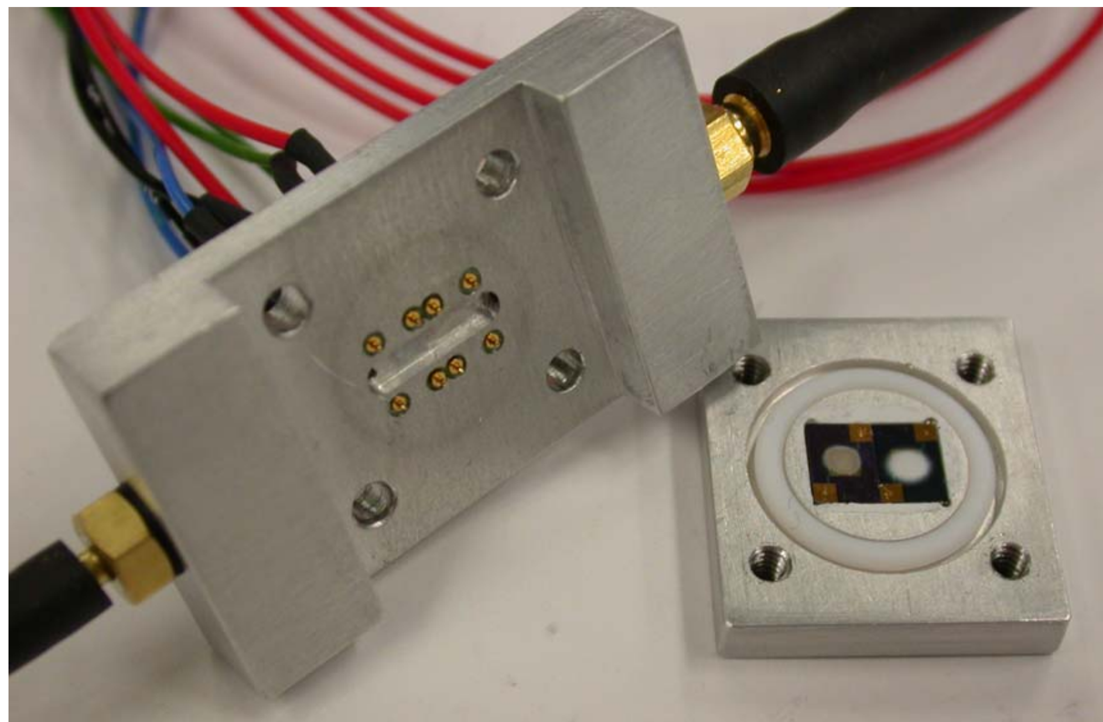
Descriptor - include initials, /org#/date

Slide courtesy of George Richards at NETL

Micro-Pellistor for BTU Determination







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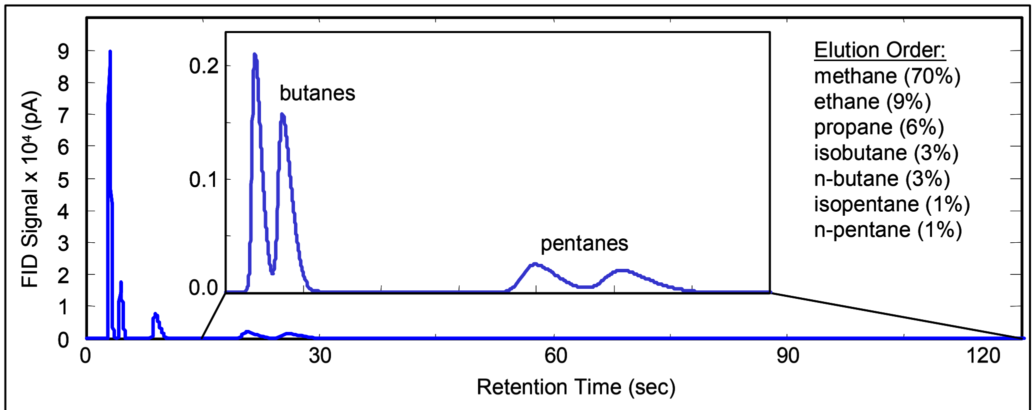
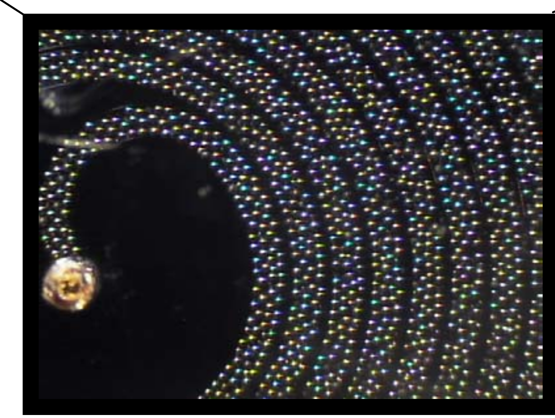
Future Directions for Micro-FIDs

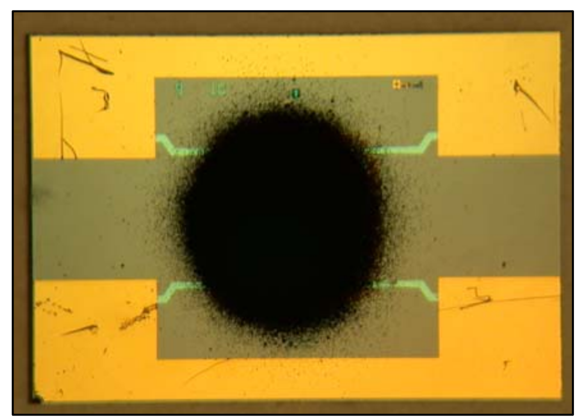


Integrate Sandia's MicroGC with the microhotplate.

- Individually measure fuel constituents.
- Reduce catalyst site competition.
- Allow calibration for each constituent's response.



GC Separation



Micro-Combustor/FID

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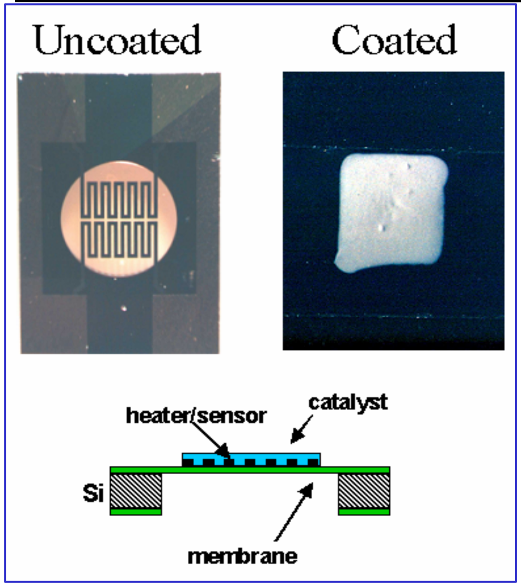
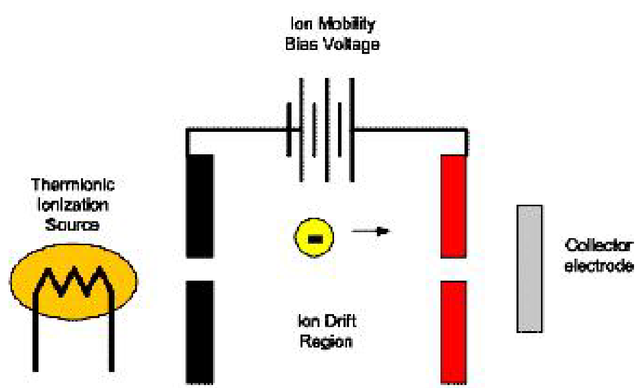
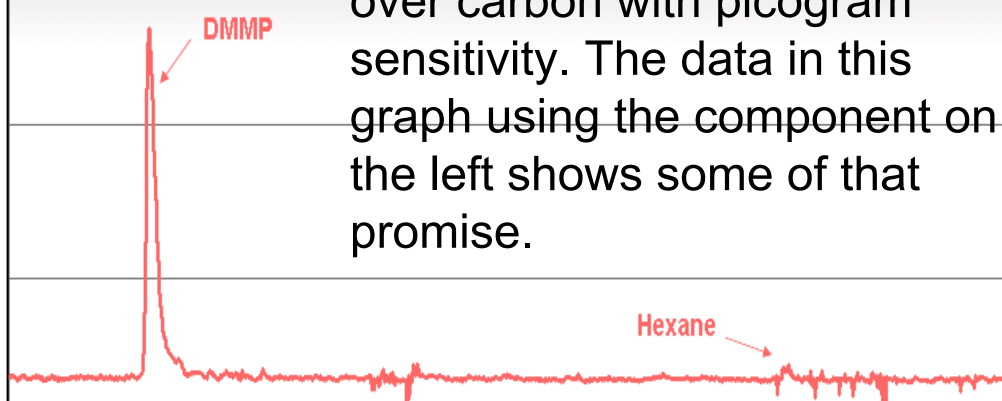
Micro-TID & Micro-NPD Development





A NPD is capable of detection N and P at a ratio of 10,000:1 over carbon with picogram sensitivity. The data in this graph using the component on the left shows some of that promise.

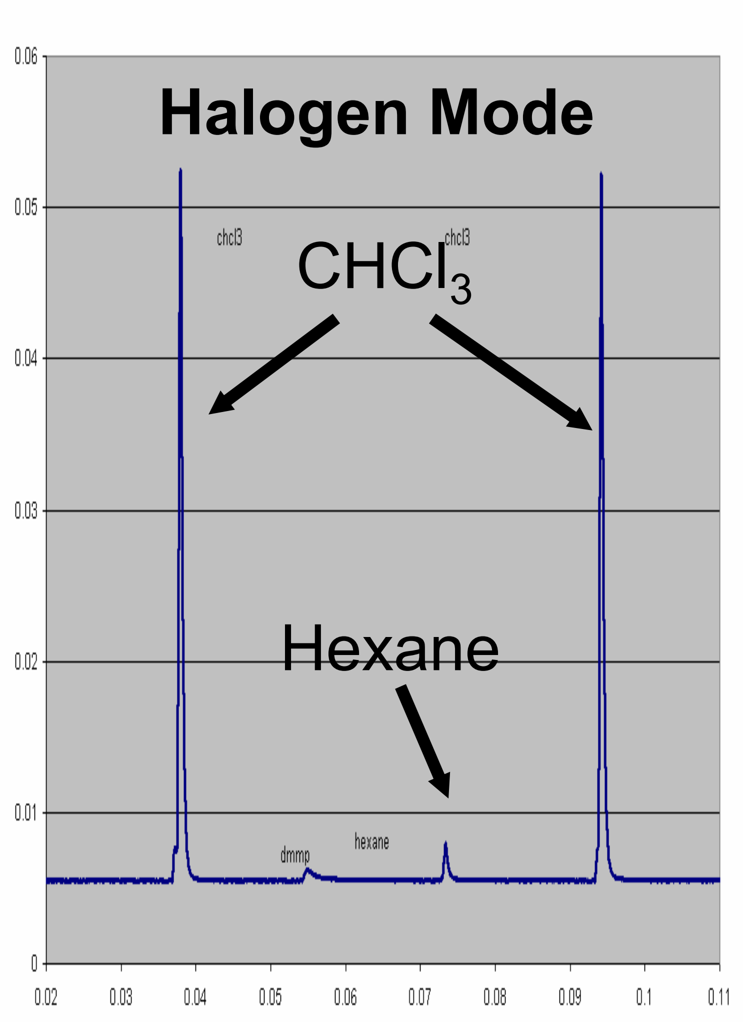


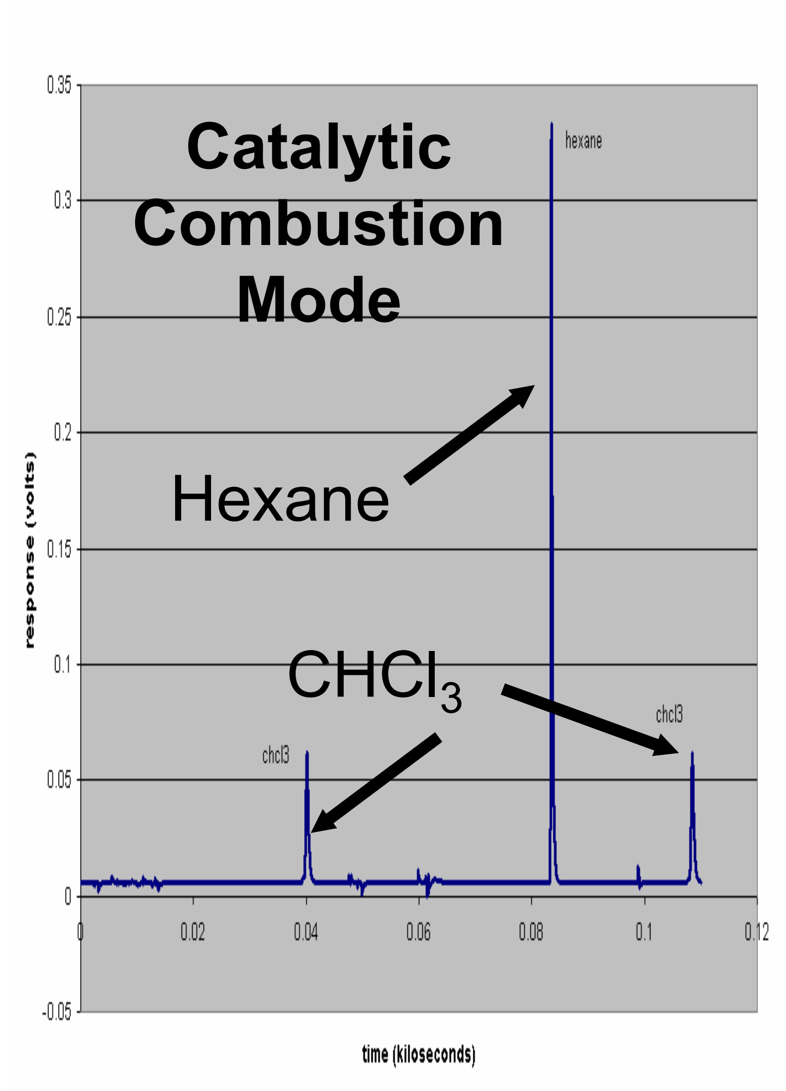
Data from these experiments will be used to design ion collection schemes on the same die to further miniaturize the NPD.

Acetonitrile was used to verify N detection but not pictured.

While detecting P requires H_2, a fully miniaturized NPD should minimize the usage of H_2. However, compounds containing nitro groups like explosives can be detected without H_2.

Surface Ionization Detector (from TID Research)



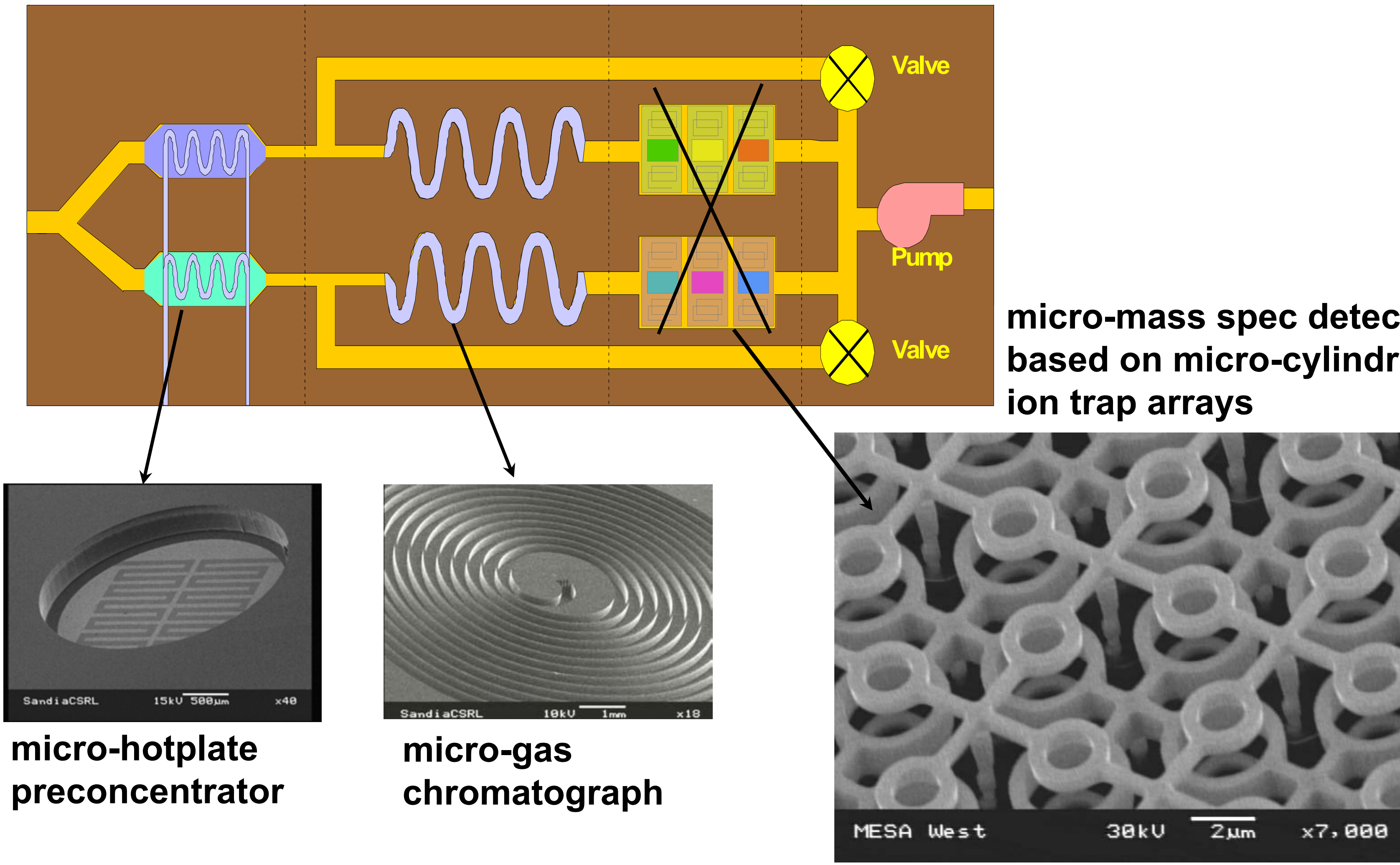


$CHCl_3$ = chloroform

Microfabricated Ion Trap Arrays

Sandia National Laboratories

Towards a Micro-GC Micro-Mass Spectrometer System



micro-hotplate preconcentrator

micro-gas chromatograph

micro-mass spec detector based on micro-cylindrical ion trap arrays

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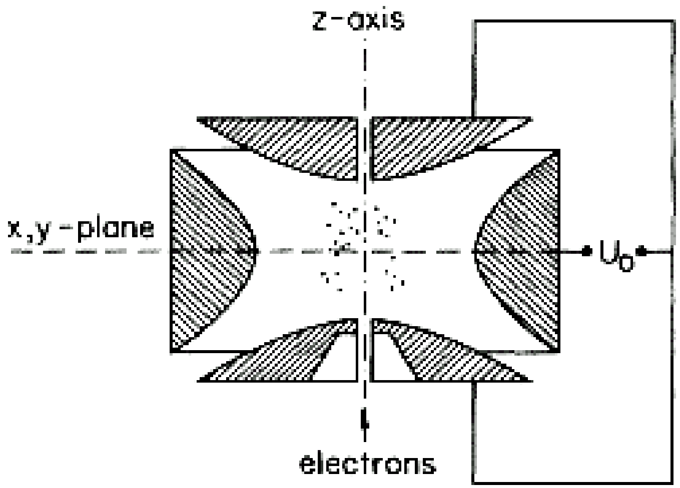
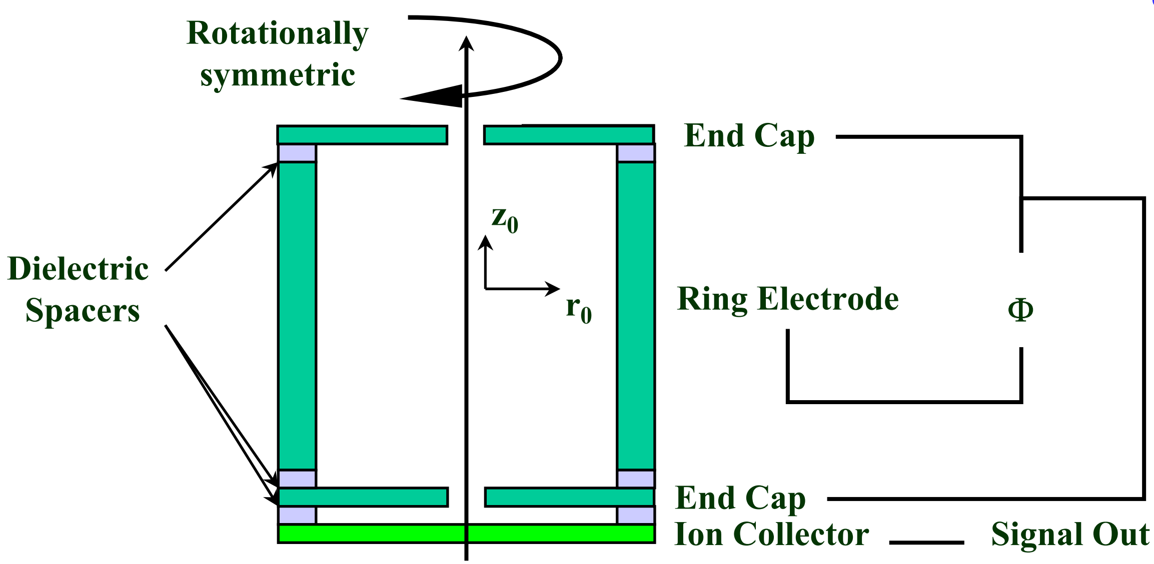
Ion Trap Function



$$m/z = \frac{8V_{rf}}{q_z(r_0^2 + 2z_0^2)\Omega^2}$$

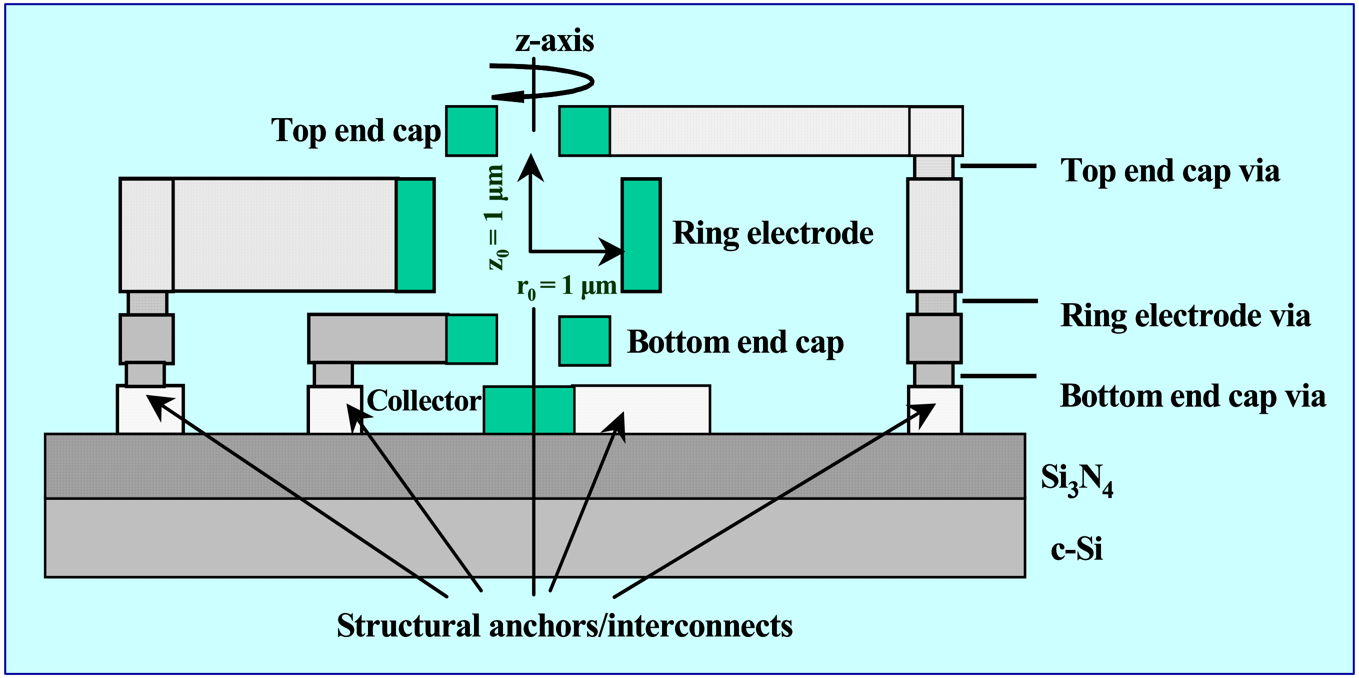


$r_0 = 5\mu m$, $z_0 = 3.5\mu m$, $V = 5\text{-}10\ V$

$q_z \leq 0.908$ (stable)

f (MHz)	m/z
100	215-430
250	35-70
500	8-17

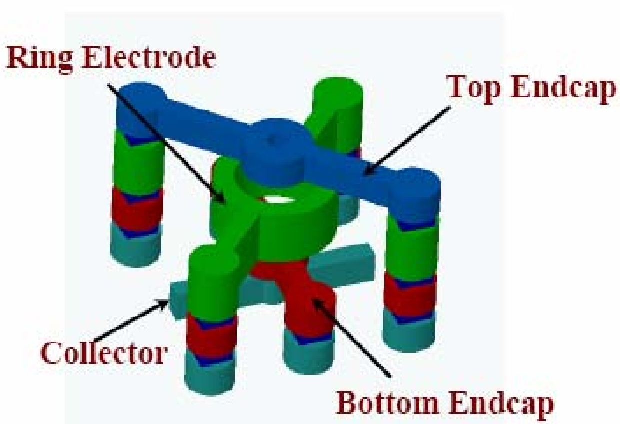
Micro-CIT Fabrication

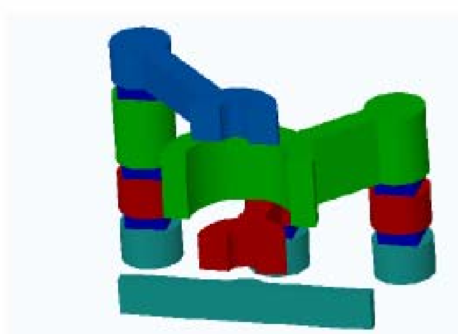


- Molded tungsten process in CMOS fab

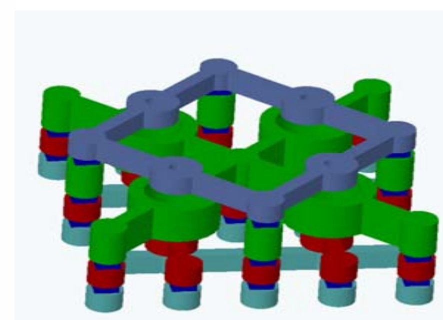
- Oxide used as mold

- Processing temps compatible with CMOS electronic fab





Cross-sectional view



Ion Trap Array

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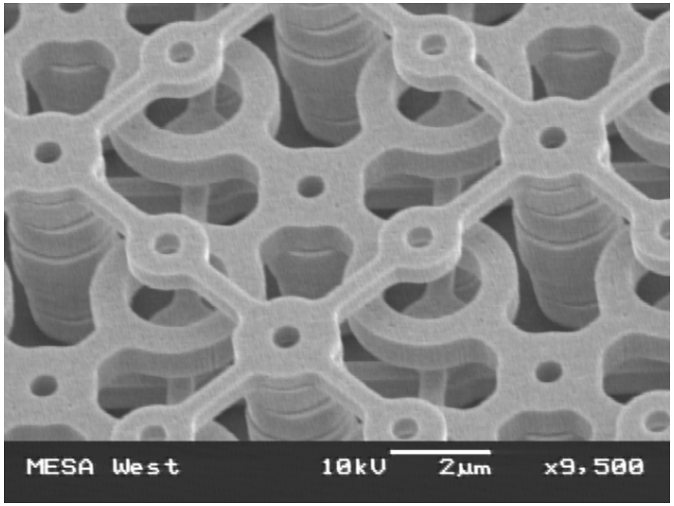
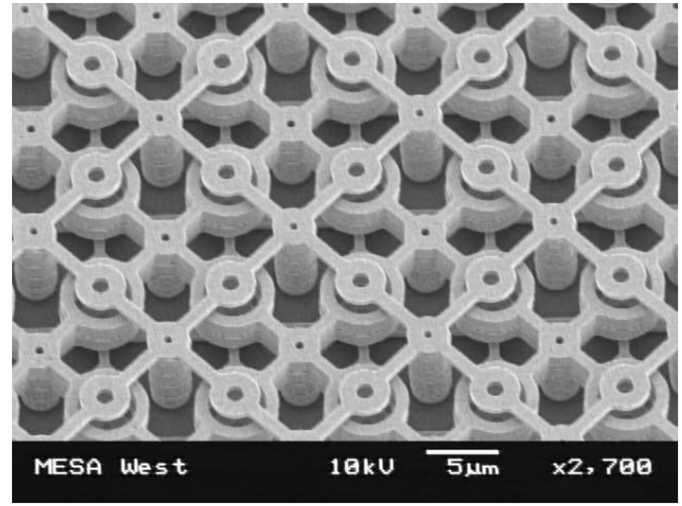
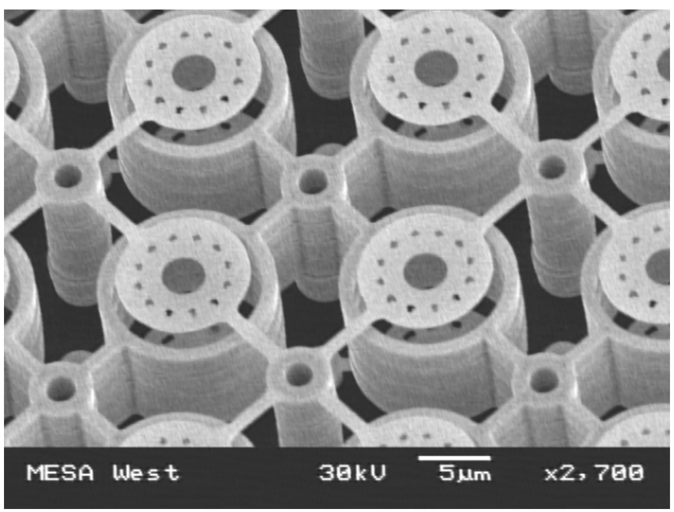
Cylindrical Ion Trap Arrays



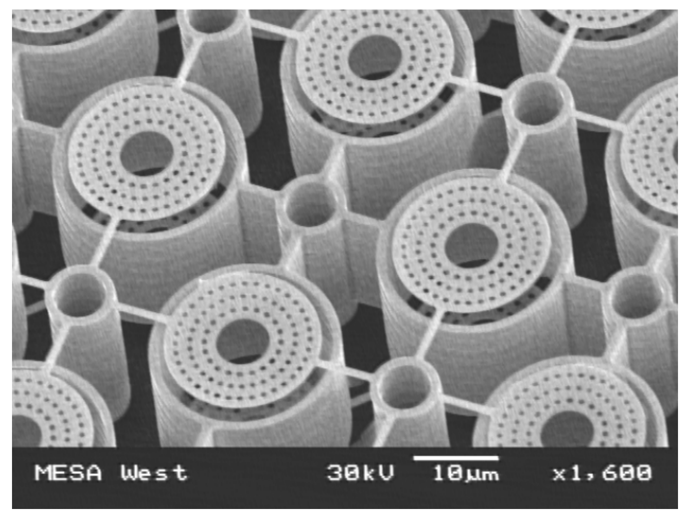
$r_0 = 1.0\ \mu m$



$r_0 = 2.0\ \mu m$



$r_0 = 5.0\ \mu m$



$r_0 = 10.0\ \mu m$

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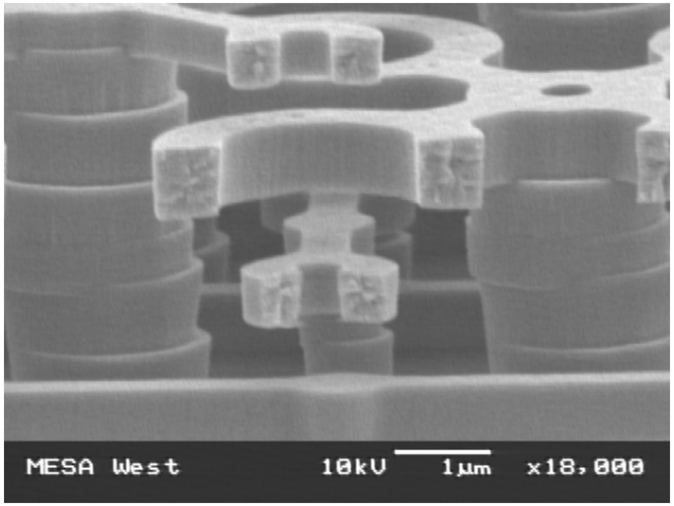
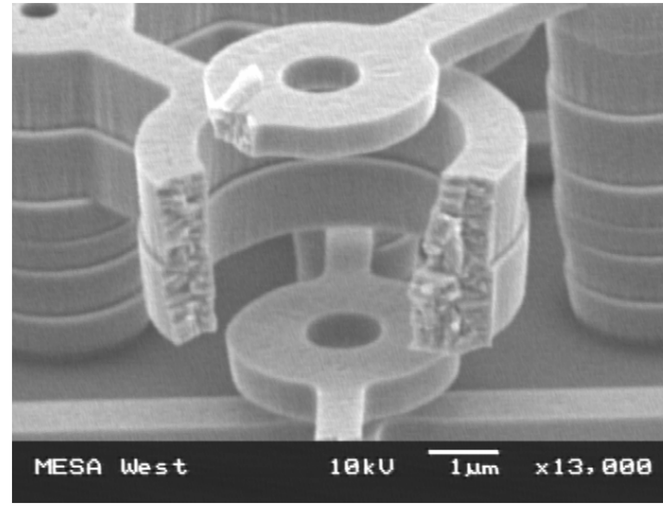
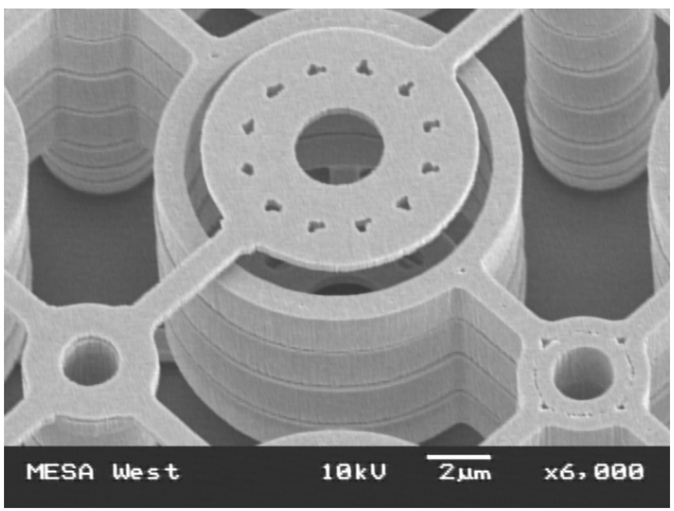
Cylindrical Ion Trap Arrays



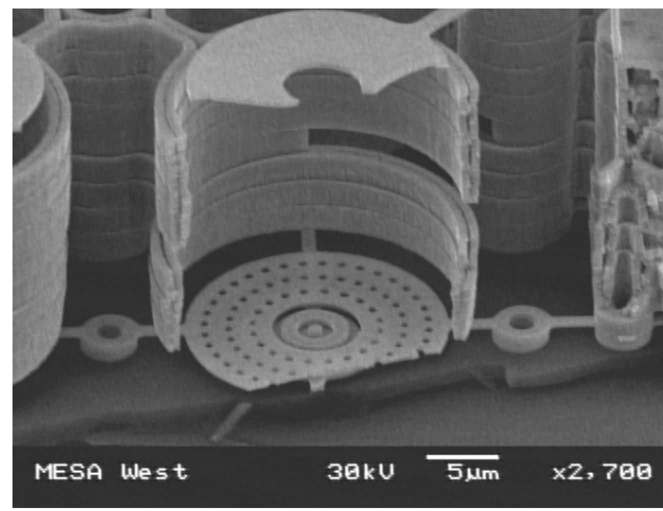
$r_0 = 1.0\ \mu m$



$r_0 = 2.0\ \mu m$



$r_0 = 5.0\ \mu m$



$r_0 = 10.0\ \mu m$

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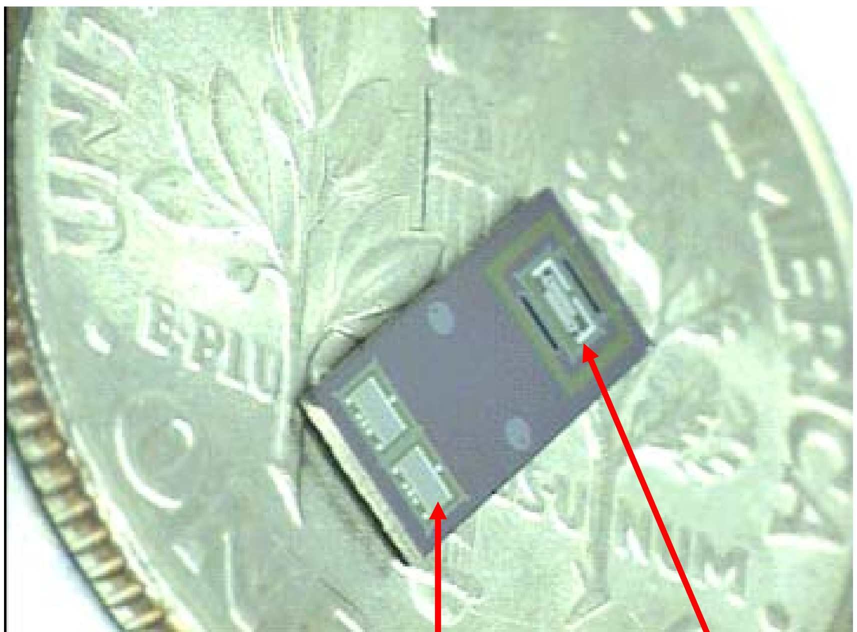
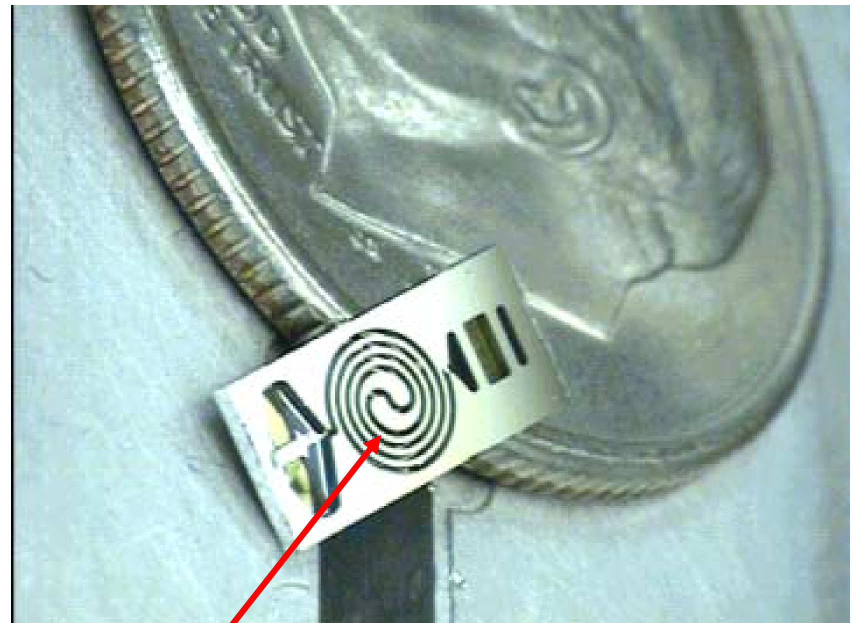
Monolithically Integrated Systems

Sandia National Laboratories

Single Substrate Integration

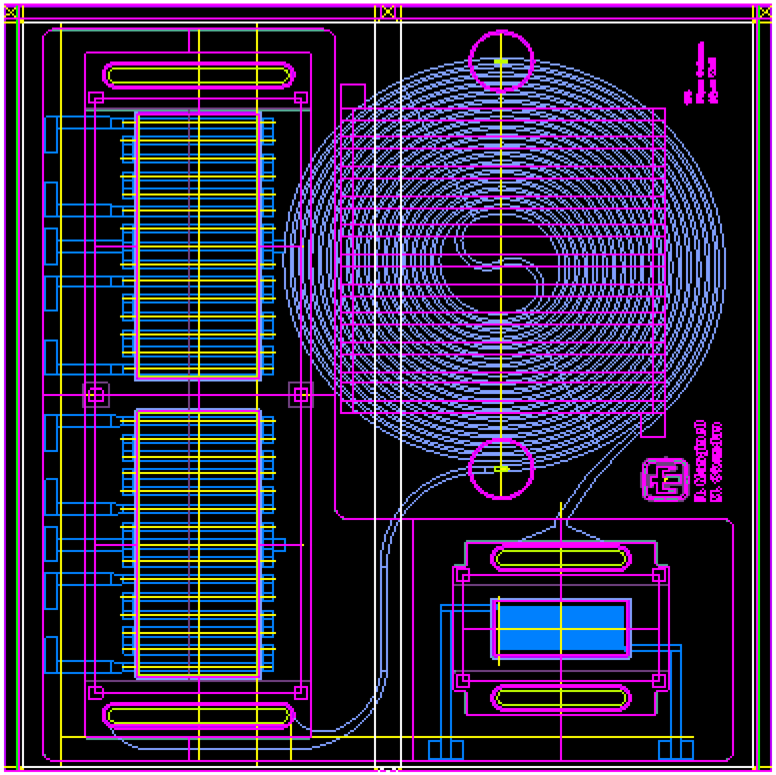
First generation of monolithically-integrated MicroChemLab™ produced in Sandia's SwiFT technology

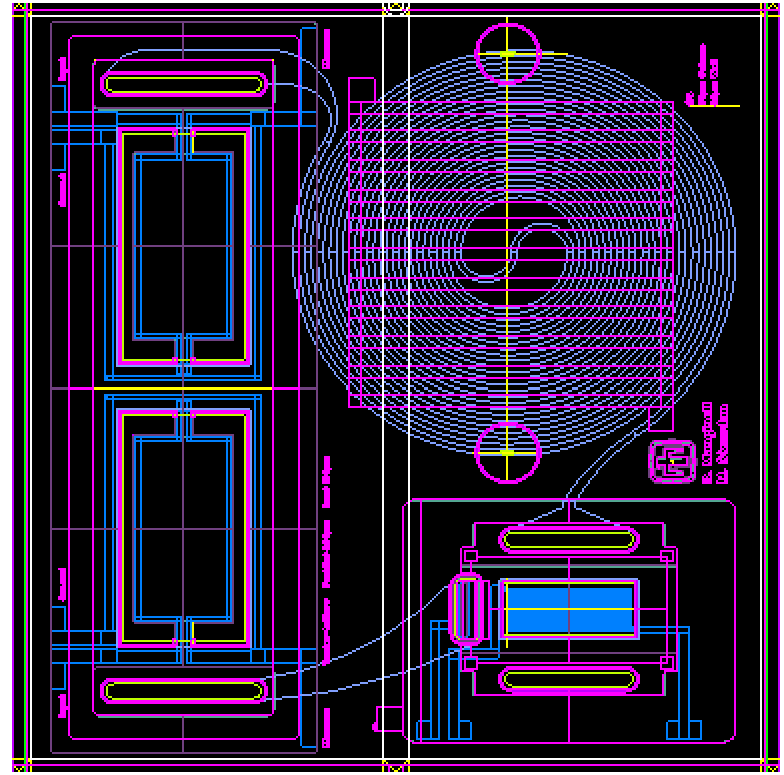




<u>Big Issue</u>: extremely temperature sensitive

New Monolithic *μChemLab*™ Designs





1st Gen System
FPW sensor, No bypass valve, 50μm channel, 50μm walls, 9.13cm long column

2nd Gen System
PPR sensor, Bypass valve, 50μm channel, 25μm walls, 11.76cm long column

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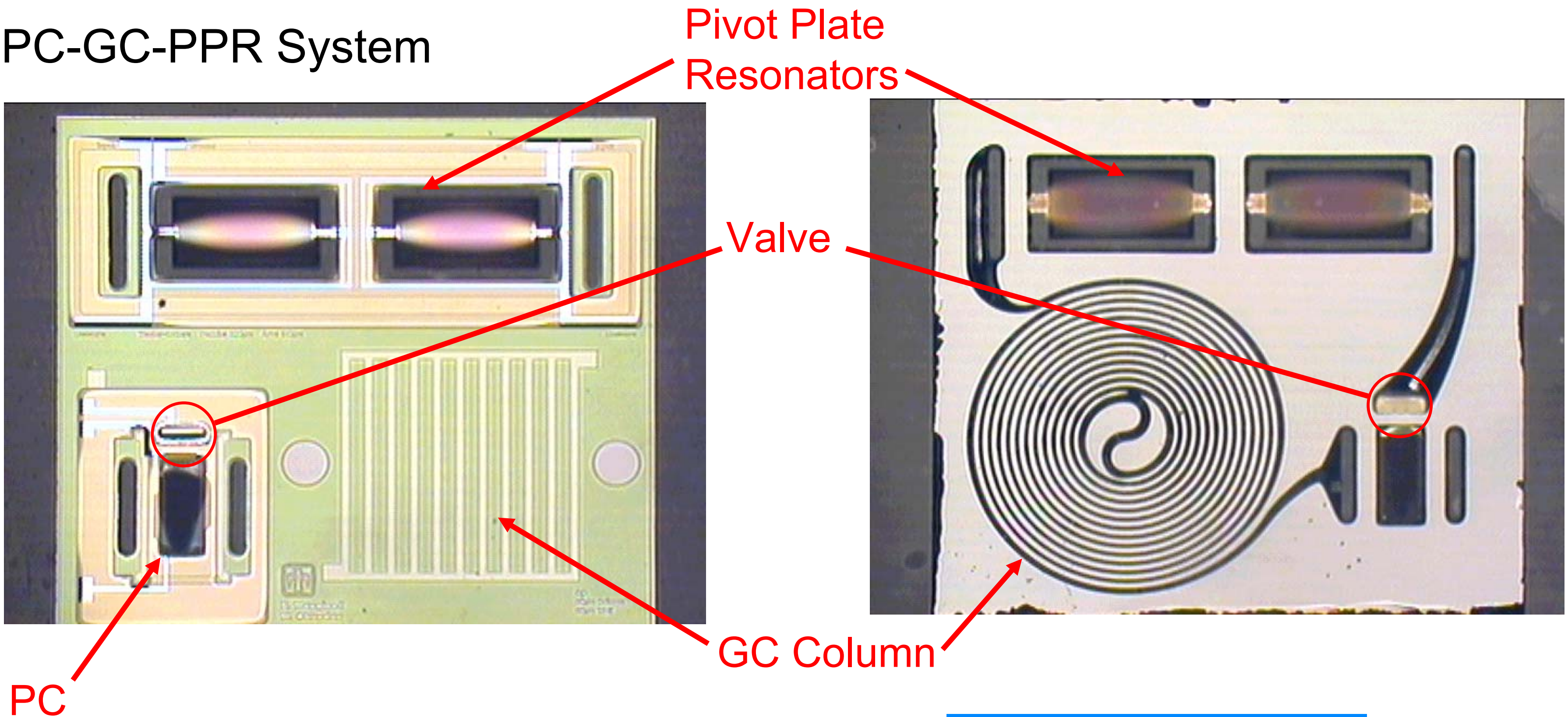
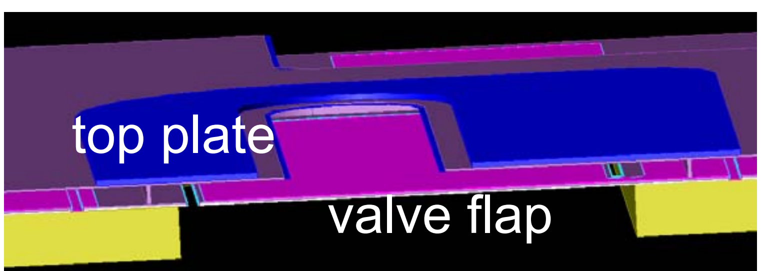
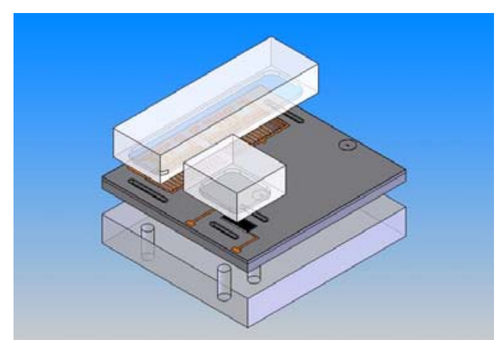
Monolithically Integrated Chemical Analysis System

PC-GC-PPR System



Valve Cross Section





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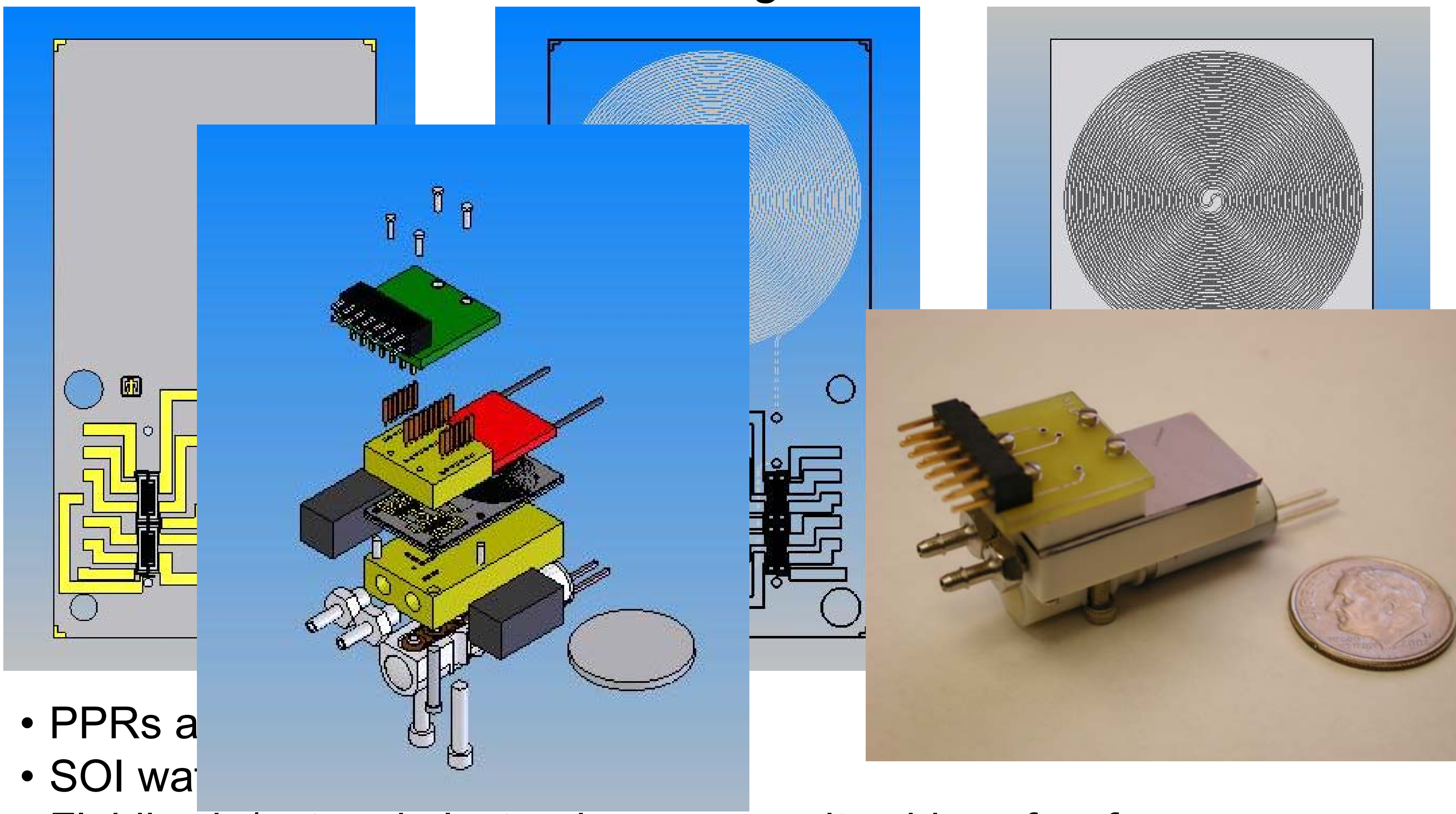
Version 4 Integrated System

Front *Through* *Back*



- PPRs a
- SOI wa
- Fluidics in/out and electronics on opposite sides of wafer
- Standard (86cm) long GC

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Questions & Discussions