A Compact, Stand-alone, Integrated MS-Vacuum Package

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Research Objective

To integrate Ceramitron's miniature double-focusing magnetic-sector MS and a non-mechanical, chemical sorption vacuum pumping system into a single, *disposable unibody* component for deployment in remote and harsh operating environments.

Design & Market Objectives

- Provide mass spectral analysis using very inexpensive, *disposable* MS sensors without sacrificing performance.
- Develop method to fabricate large quantities of “identical” devices using alternative materials and a fully-automated manufacturing process that exploits currently available PCB and integrated circuit packaging to reduce manufacturing costs.
- Eliminate expensive mechanical vacuum pumps, gages and enclosures.
- Achieve the highest performance/price in the industry!

Design Approach

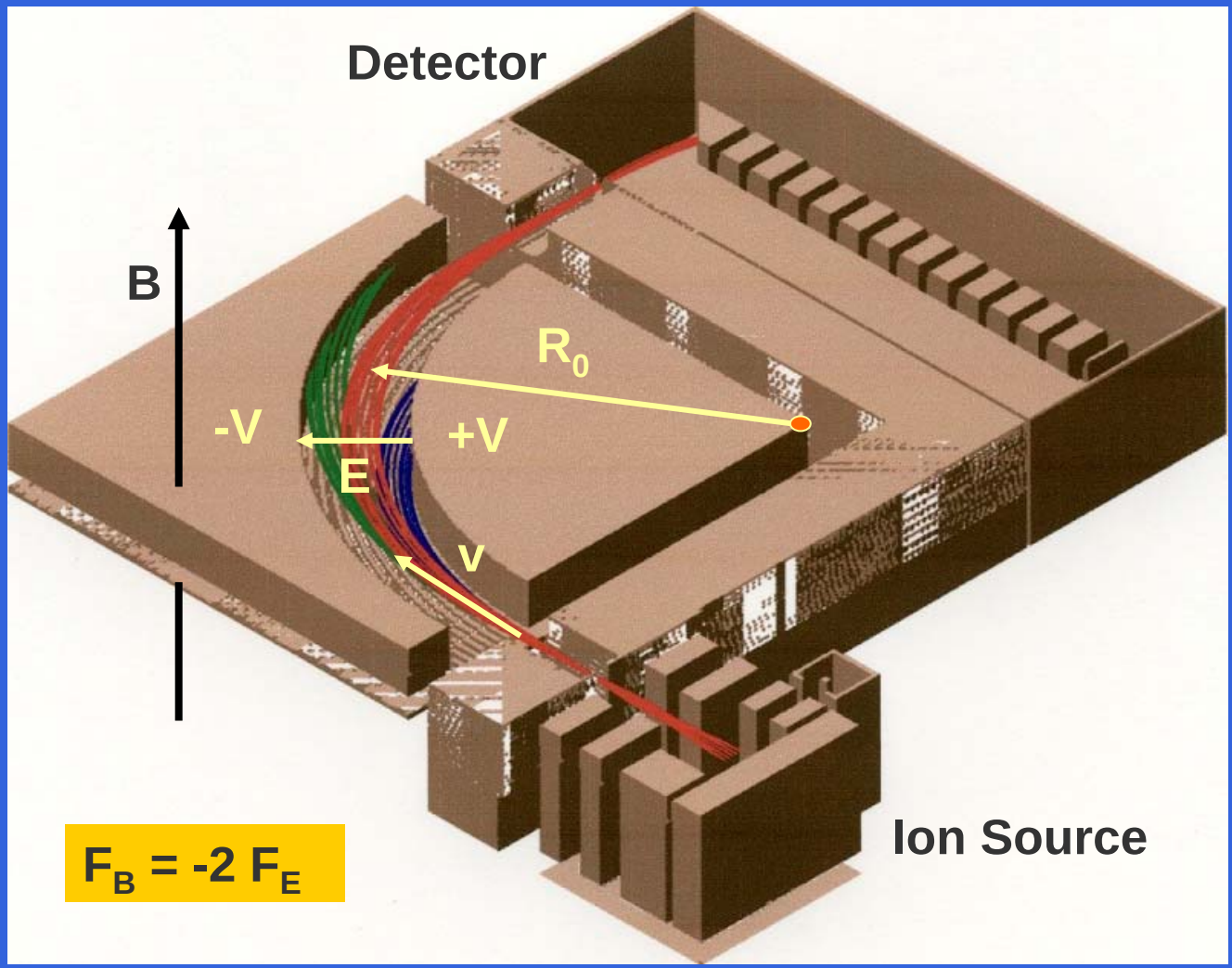
- Convert MS from discrete to photolithographic design
- Eliminate vacuum chamber by using sensor enclosure
- Replace mechanical pumps with sorption vacuum pumps
- Integrate vacuum pumps into sensor enclosure
- Eliminate vacuum gage by monitoring IP Penning current
- Add gas flow restrictor to simplify pulsed-valve inlet
- Miniaturize electronics to surface-mount multi-layer design
- Network units into a distributed sensor array

The Technology

- Miniature double-focusing mass spectrometer* constructed entirely from 3 FR4 fiberglass plates comprises sensor enclosure *and* vacuum chamber.
- Discrete metal elements replaced by photolitho-graphic metallization on internal walls.
- Ion pump (IP) and non-evaporable getter (NEG), integrated into the housing, replace external mechanical vacuum pumps.

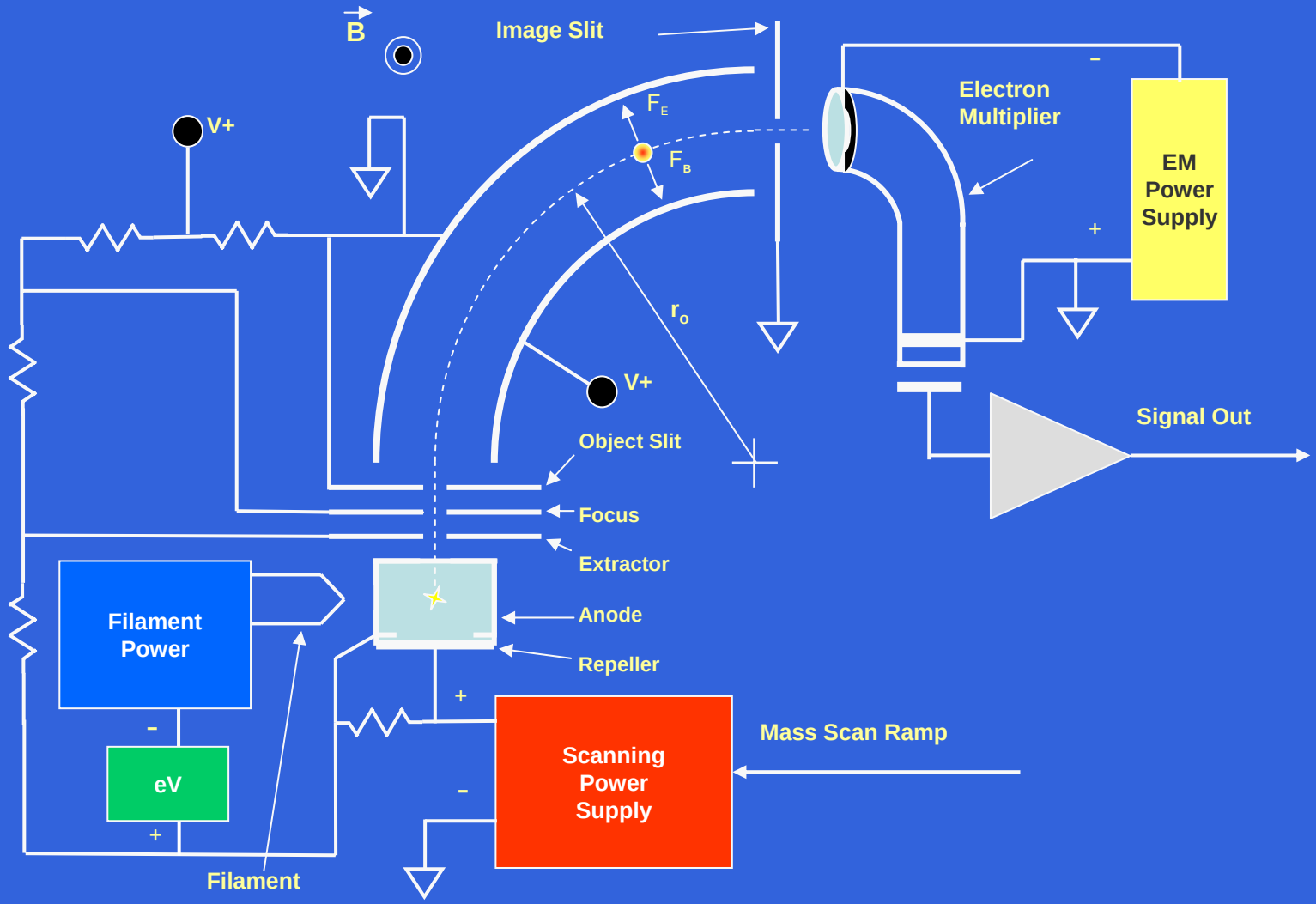
*** US Patents 6,590,207 6,831,276**

90° ExB Double-focusing MS Geometry



$$m/z = \frac{k\ B^2\ R_o^{\ 2}}{V_{acc}}$$

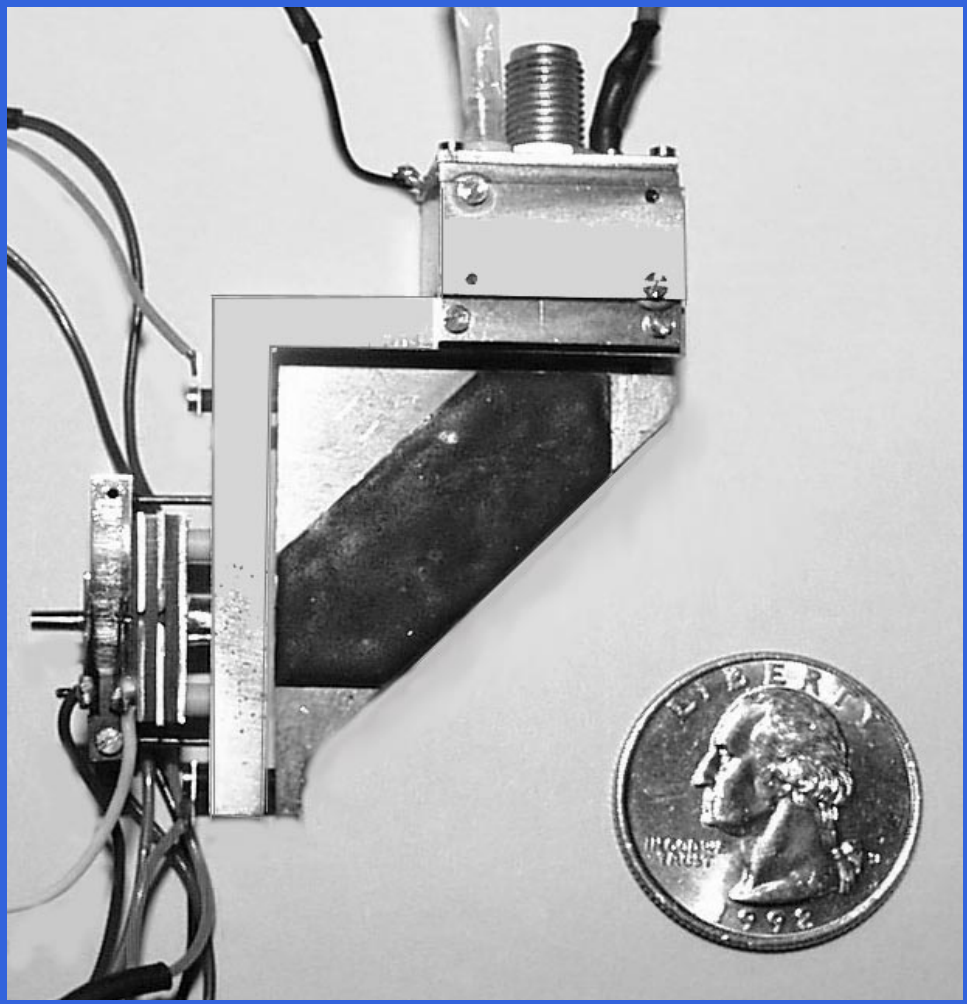
Courtesy University of Minnesota



Simplified Electrical Block Diagram

Compact Control Electronics

Proof of Concept



Courtesy University of Minnesota

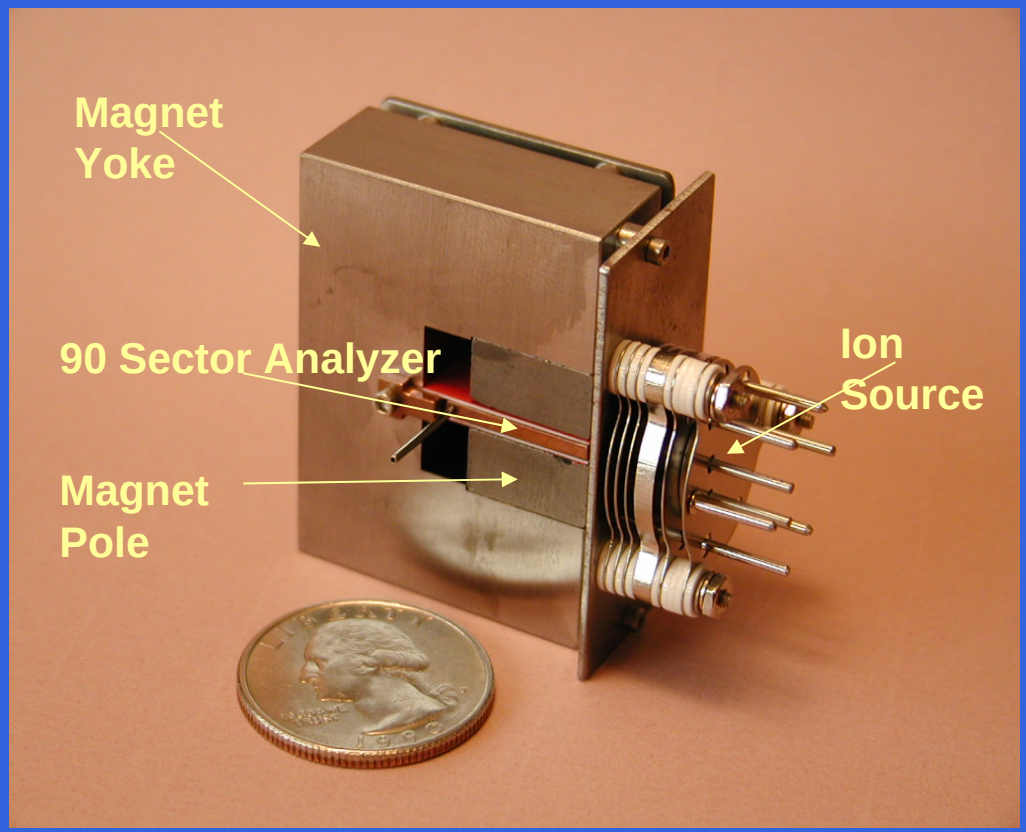
DOUBLE-FOCUSING MASS SPECTROMETER

Proof-of-Concept

Developed at Univ. of Minnesota, ca.1998.

US Patent 6,501,074 issued Dec. 31, 2002.

Discrete-Element Sensor



Courtesy Mass Sensors, Inc.

Mass range: 1-50 amu

Resolution: 45

Ionization: electron impact

Sensitivity: 1-5 ppm

Weight: 150g

Construction:

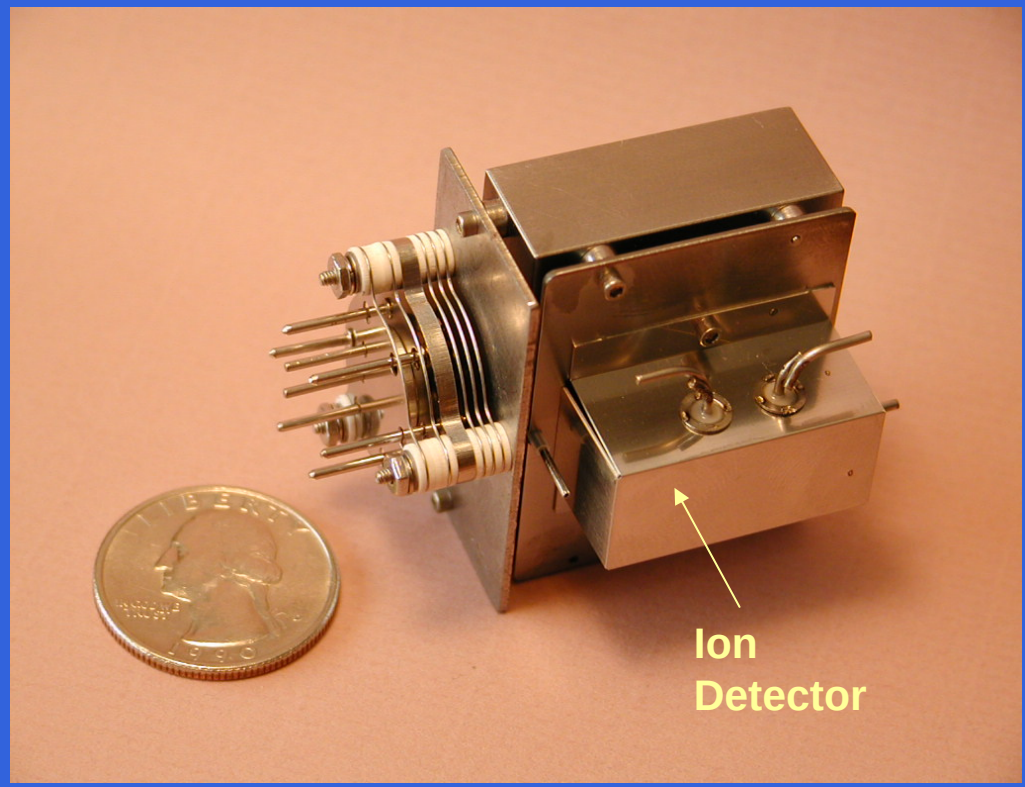
-- machined elements

-- manual assembly

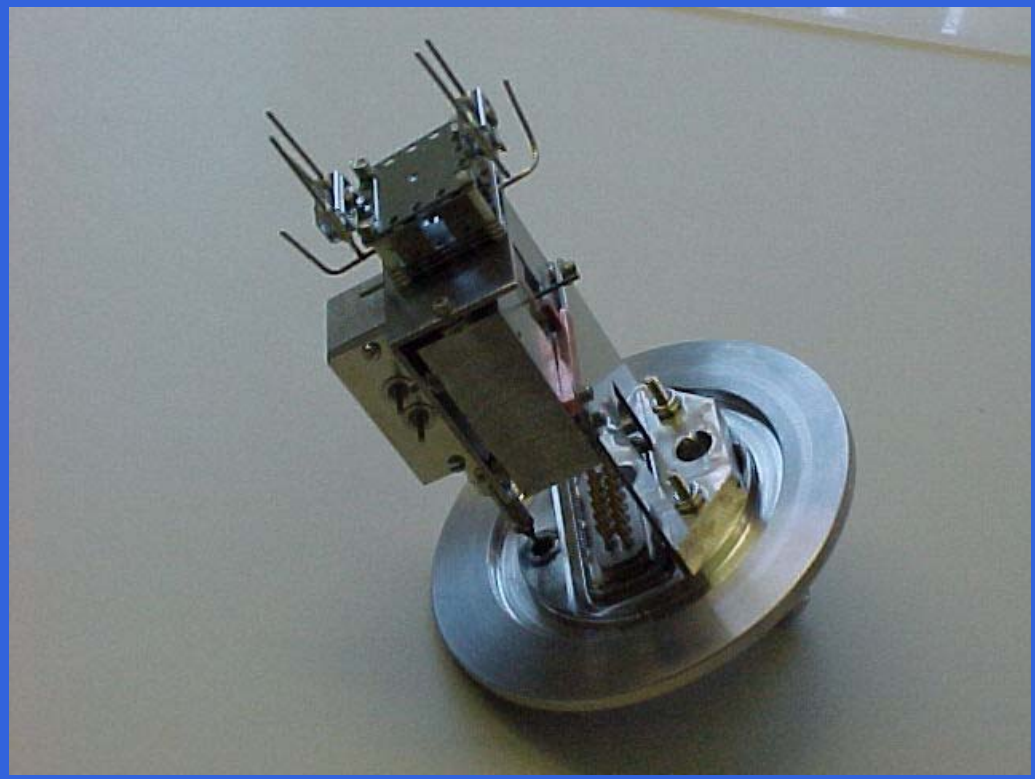
-- precision alignment

-- requires vacuum chamber

Discrete-Element Sensor



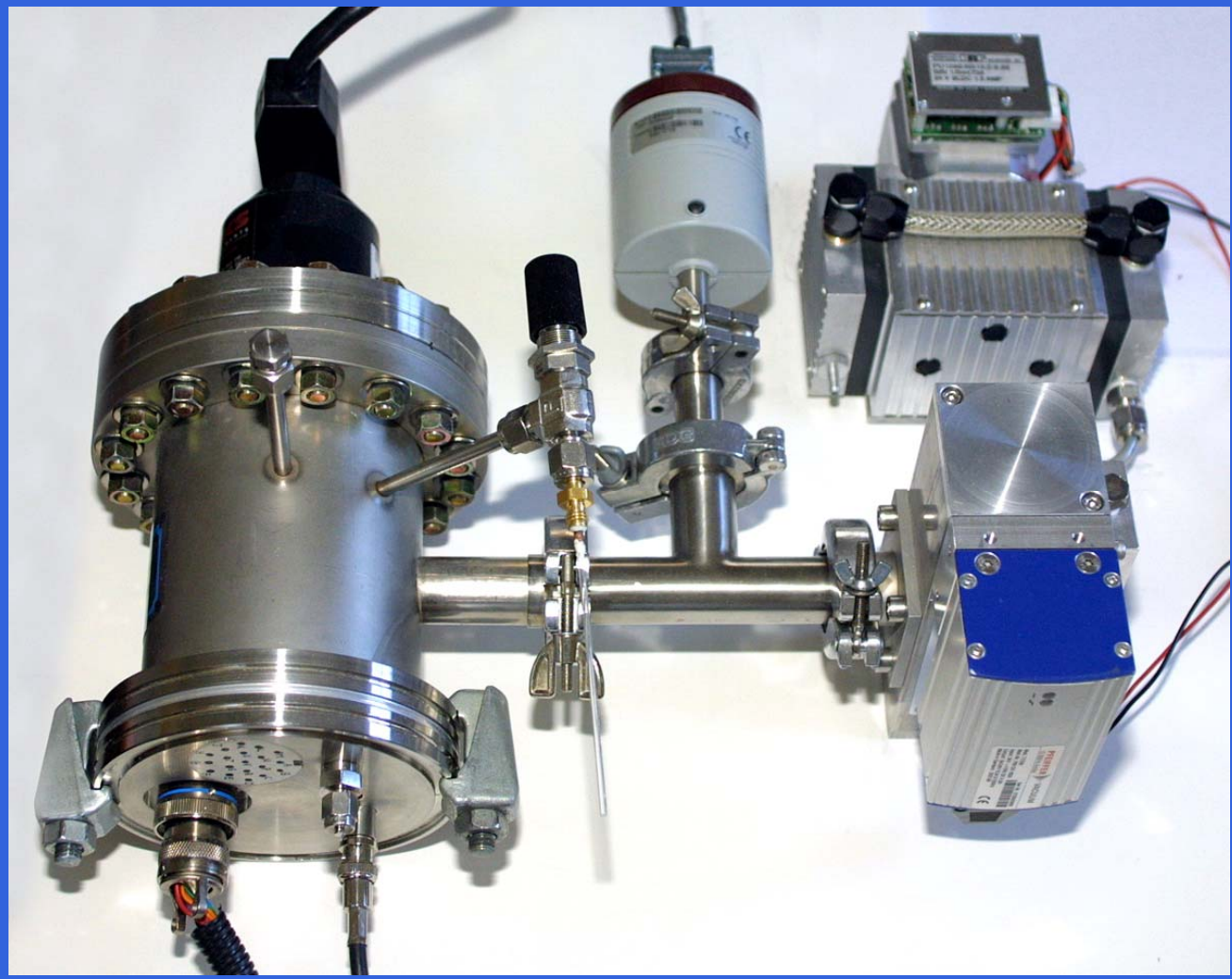
Courtesy Mass Sensors, Inc.



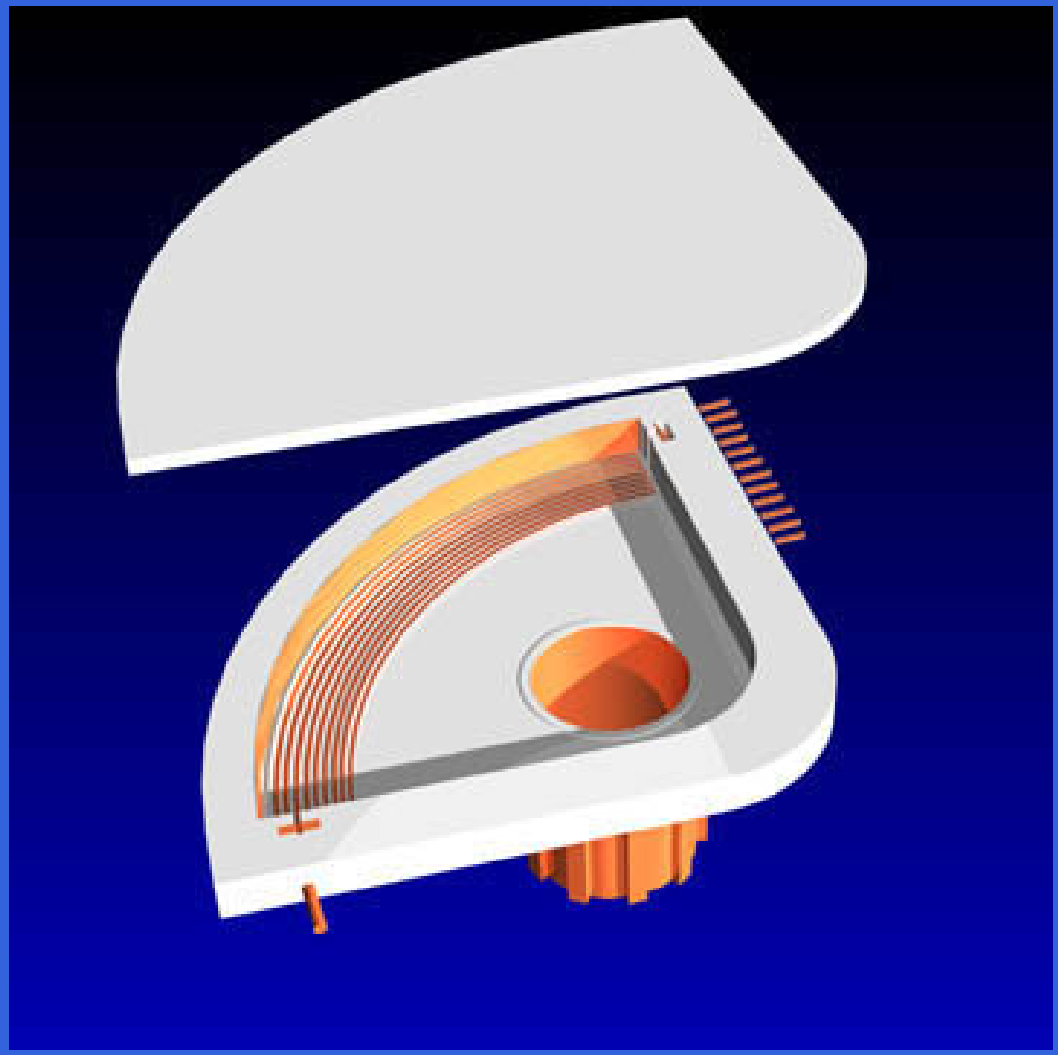
Courtesy Mass Sensors, Inc.

Sensor mounted on standard vacuum flange

Conventional Vacuum System

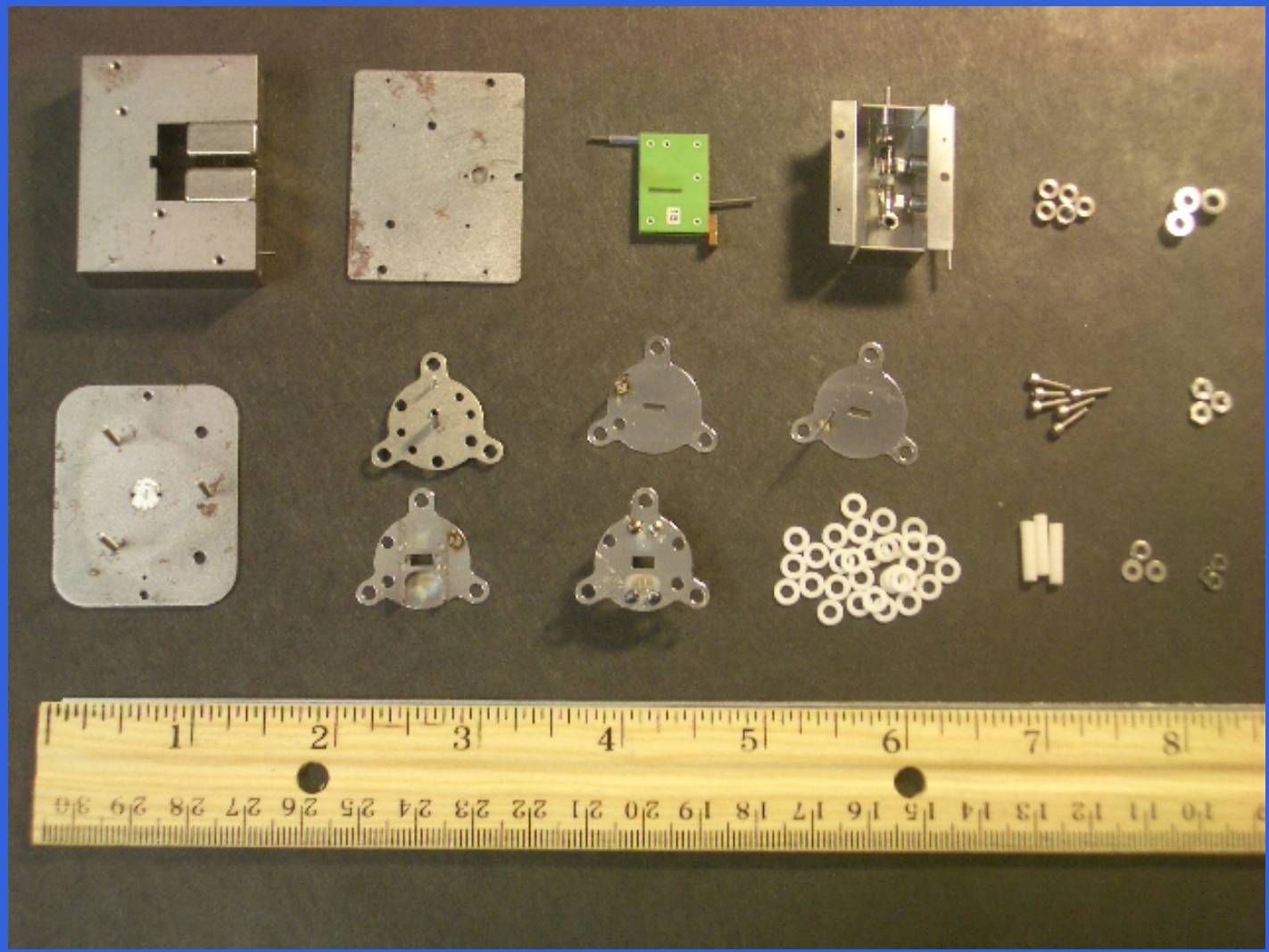


Next Generation Sensor Concept

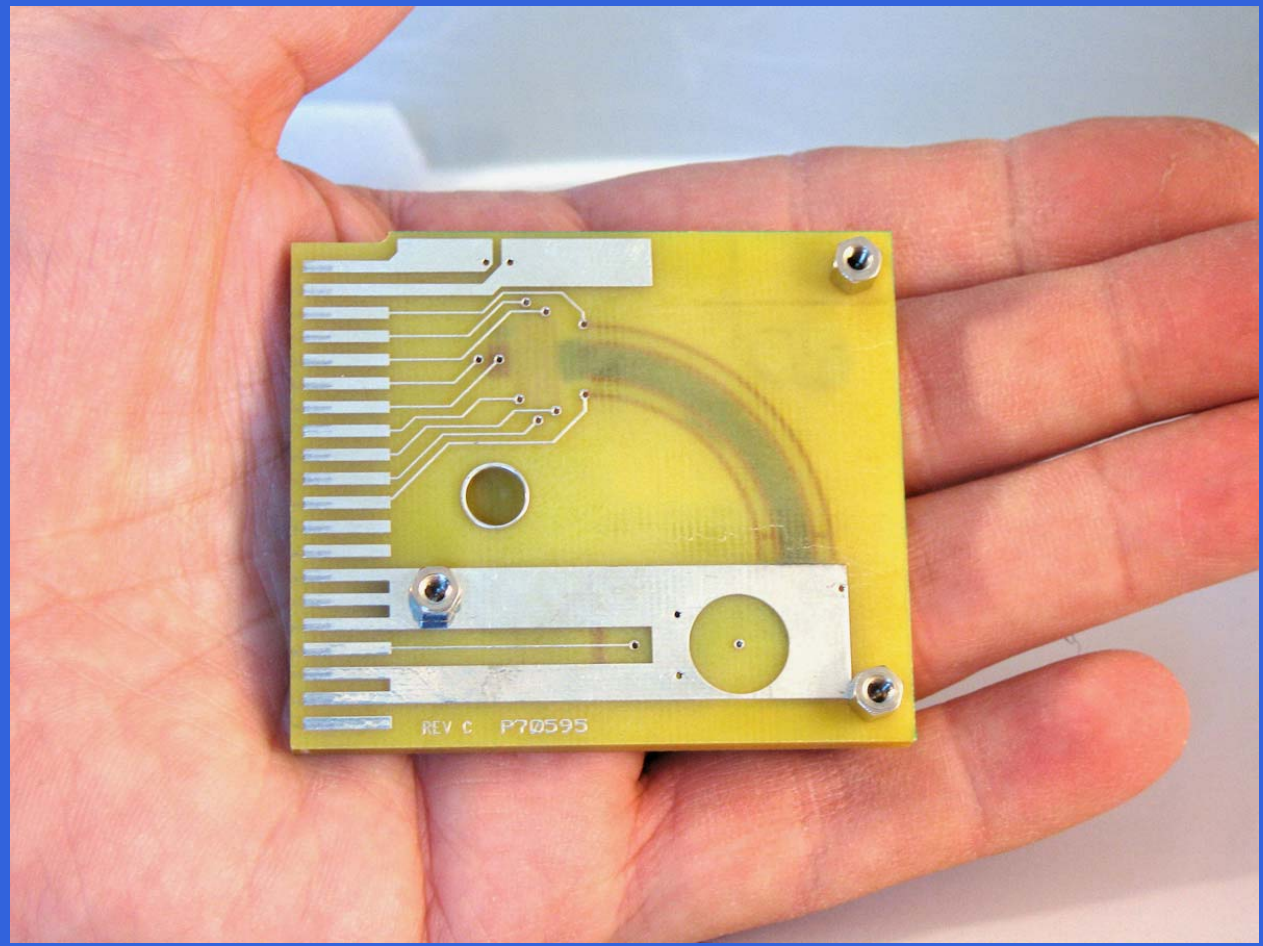


eramitron

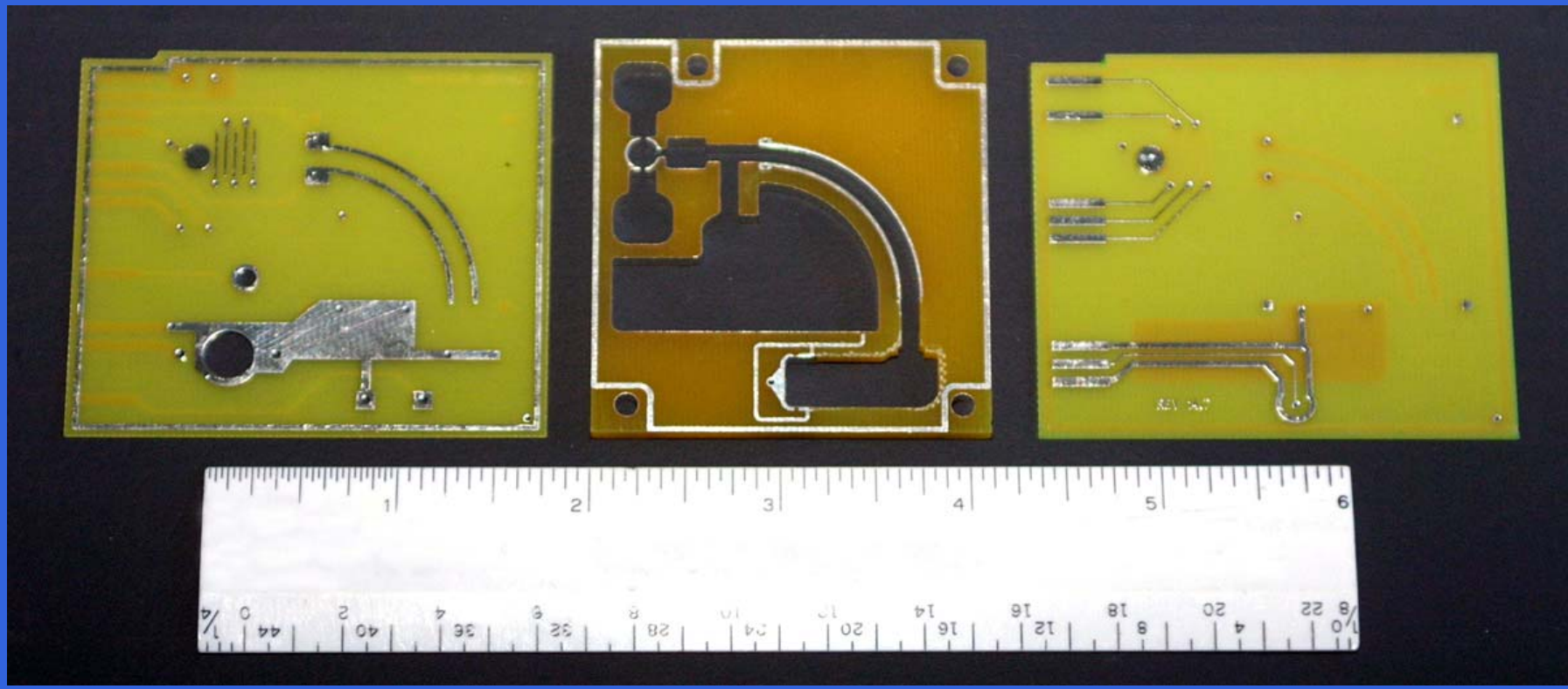
Prior-Art: Discrete Machined Parts



Fiberglass Sensor Prototype

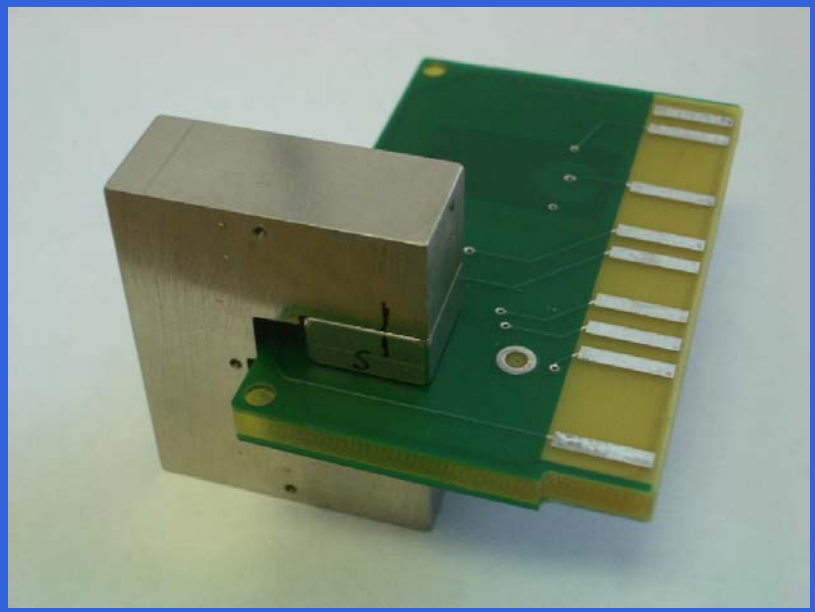


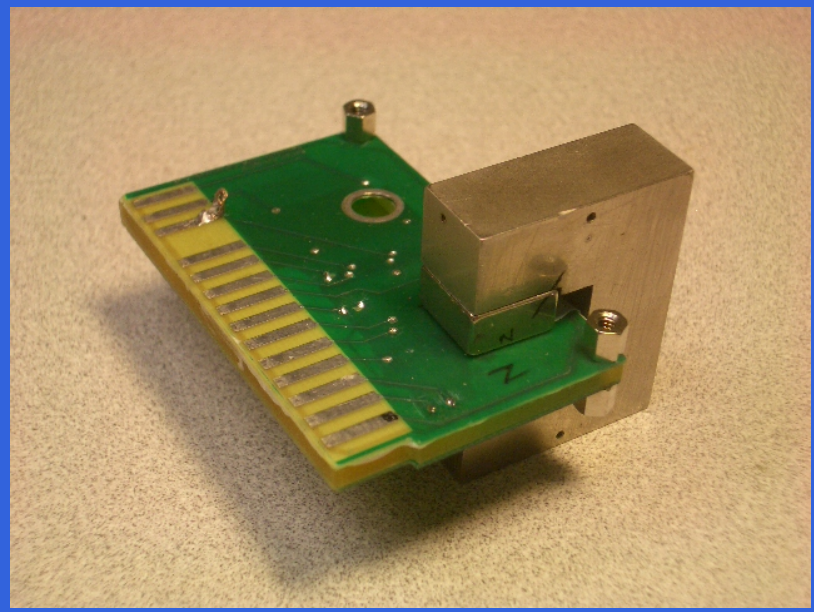
Fiberglass Mass Spectrometer



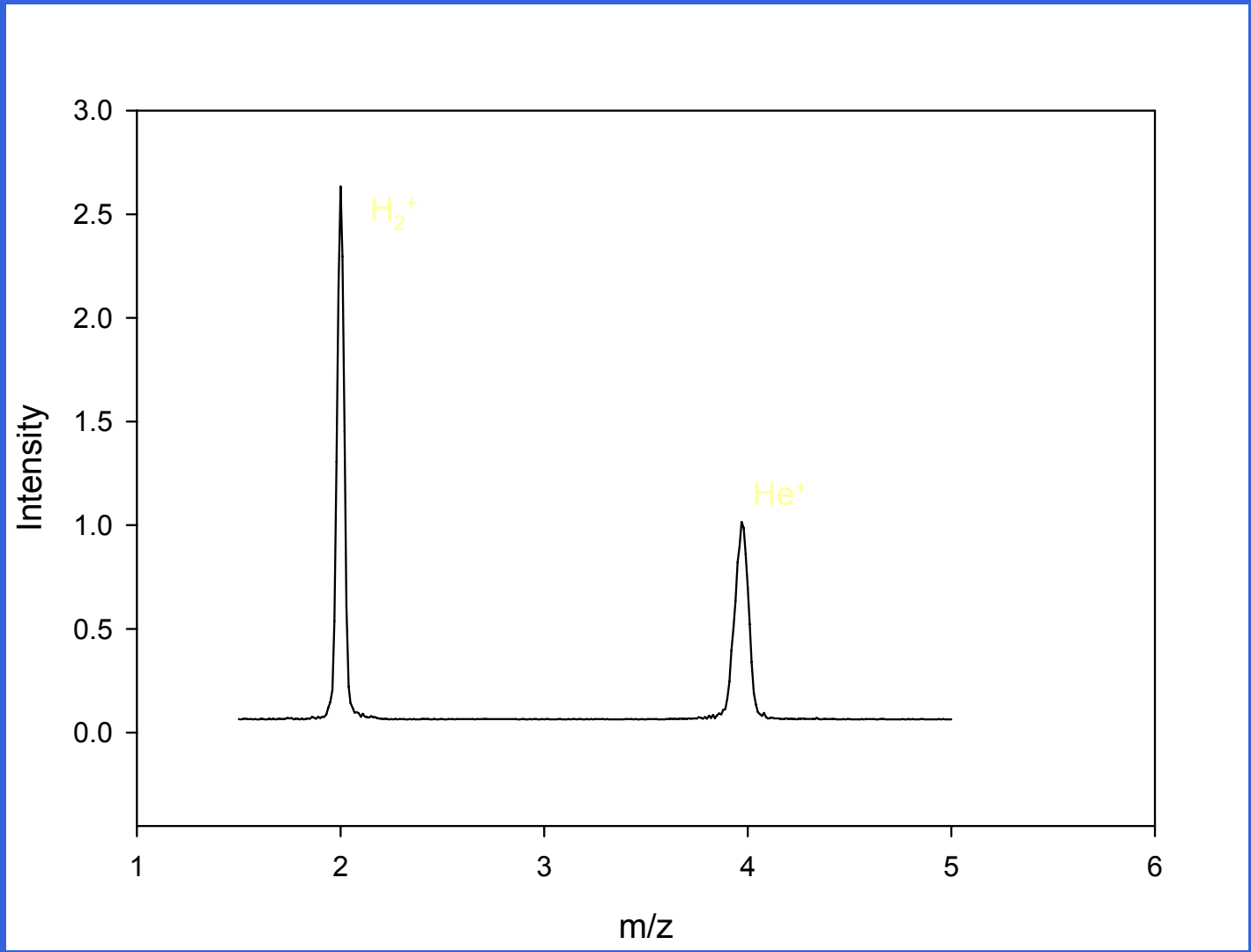
Elements With Solder-Seal Rings

8mm Helium-Hydrogen Sensor



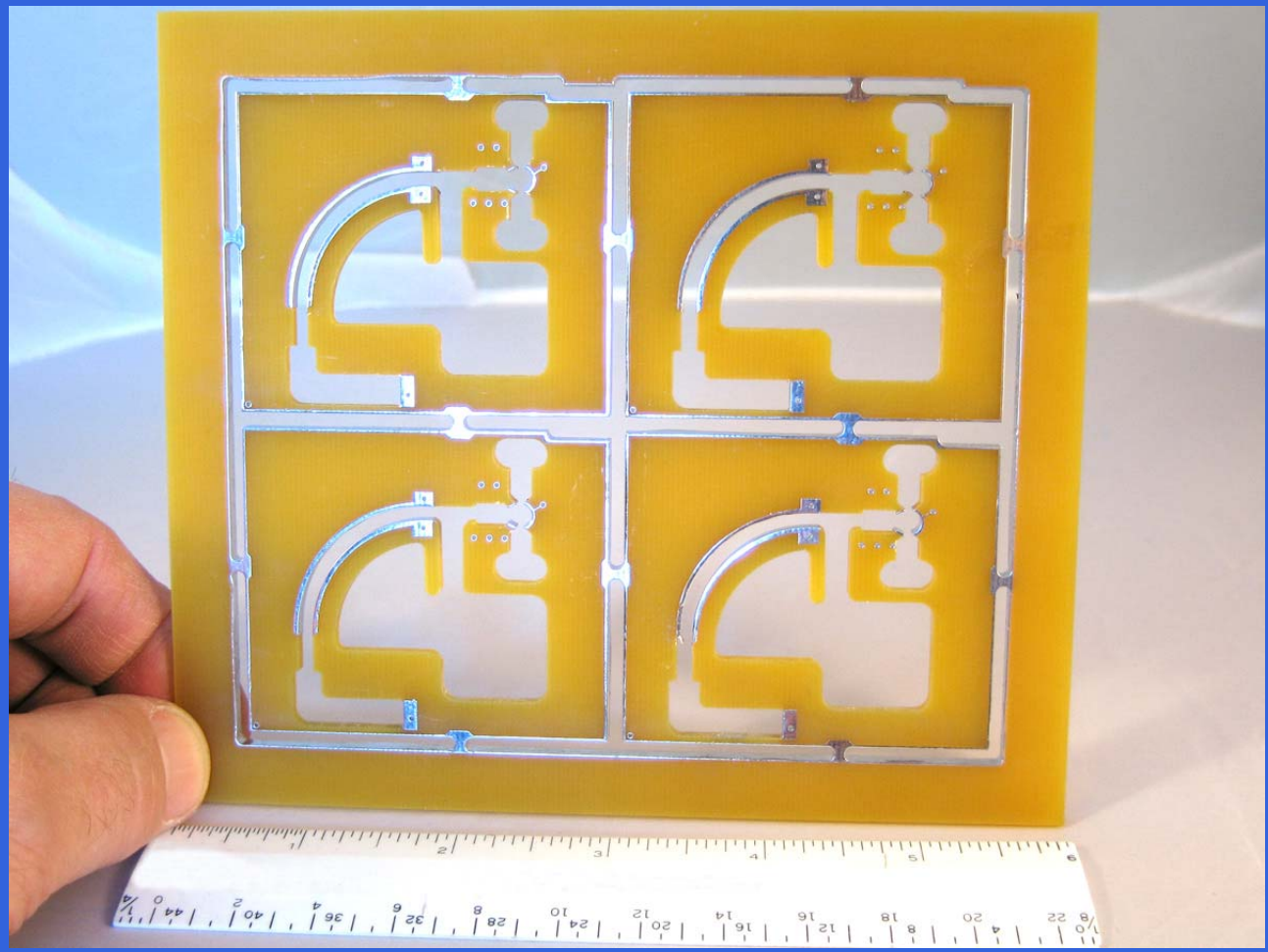


Card-edge Connector Provides Operating Voltages

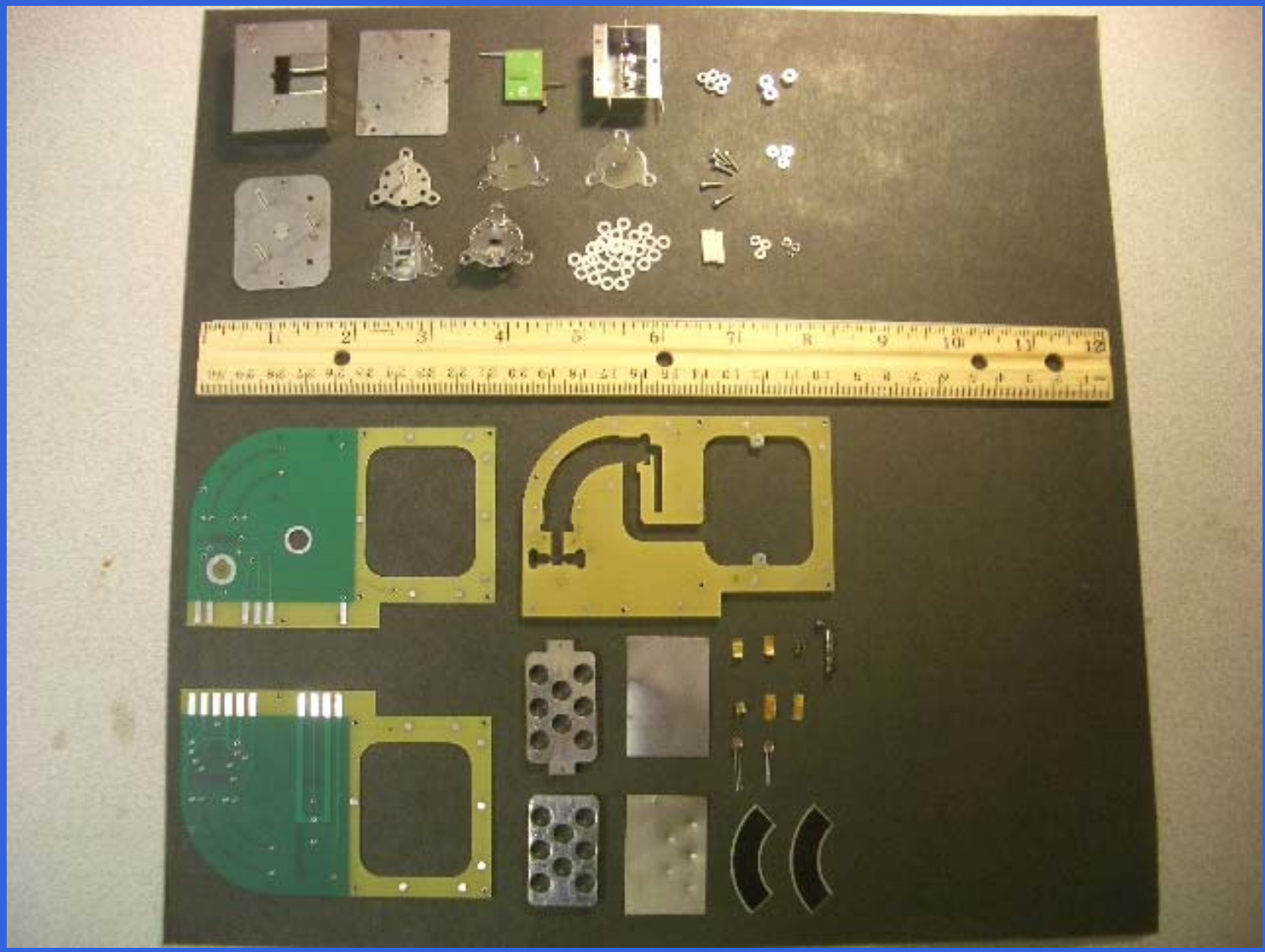


Hydrogen and helium are highly resolved

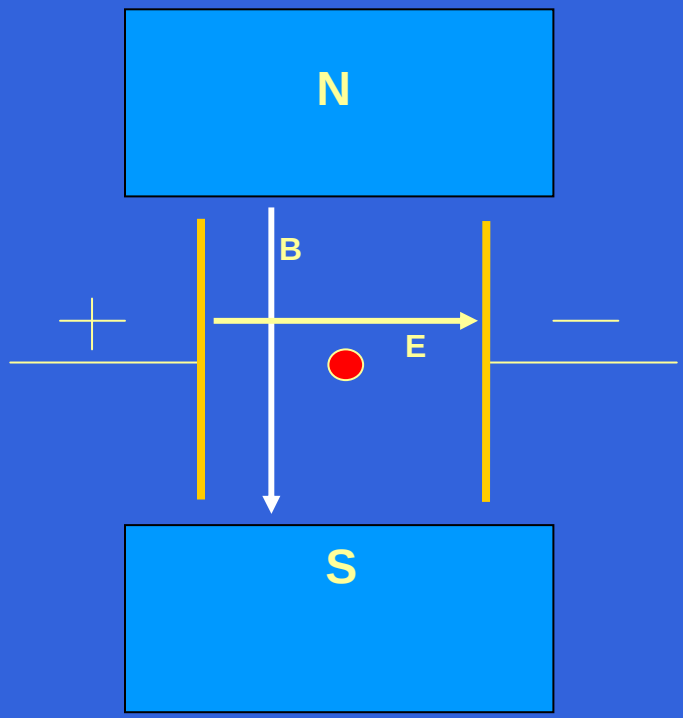
Multi-Sensor Fabrication



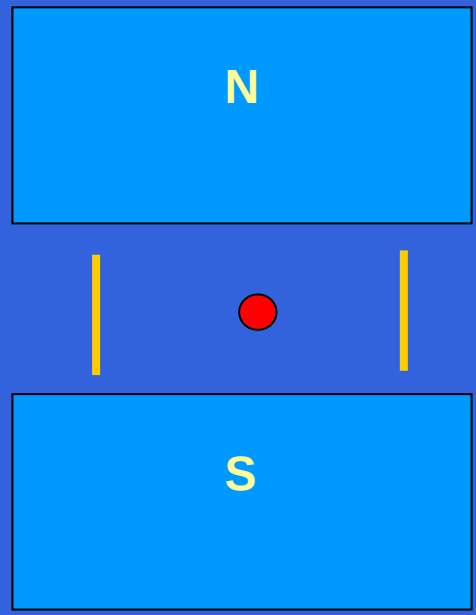
Discrete vs. Photolithographic



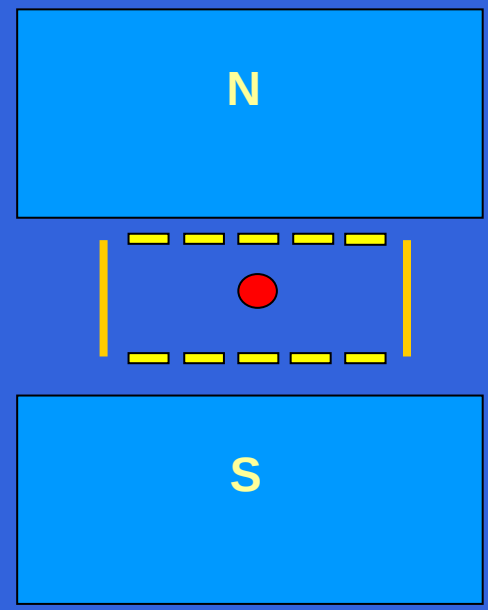
Morphing to Simplify



Traditional E-Sector

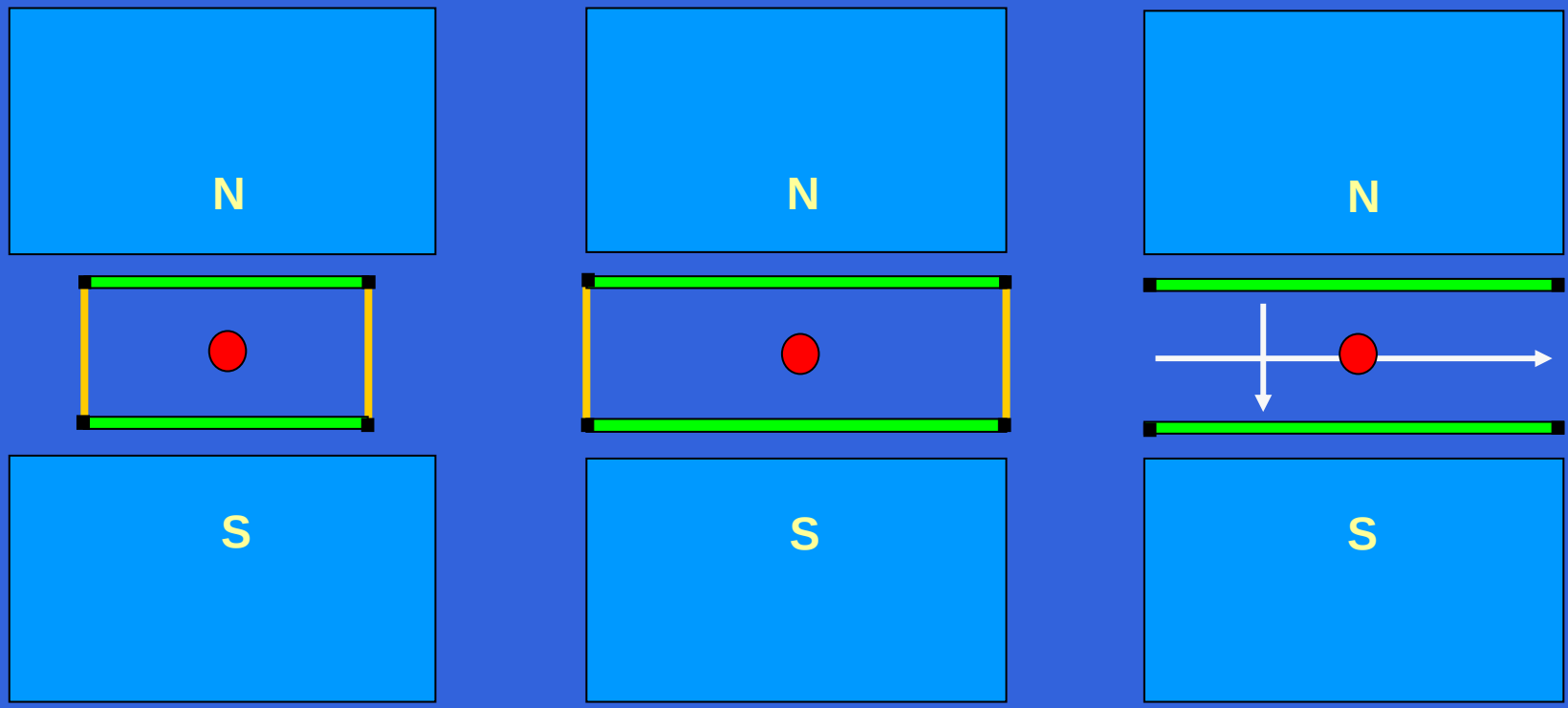


Smaller magnet gap
to increase B-field



Discrete elements
correct fringe E-field

Morphing to Simplify

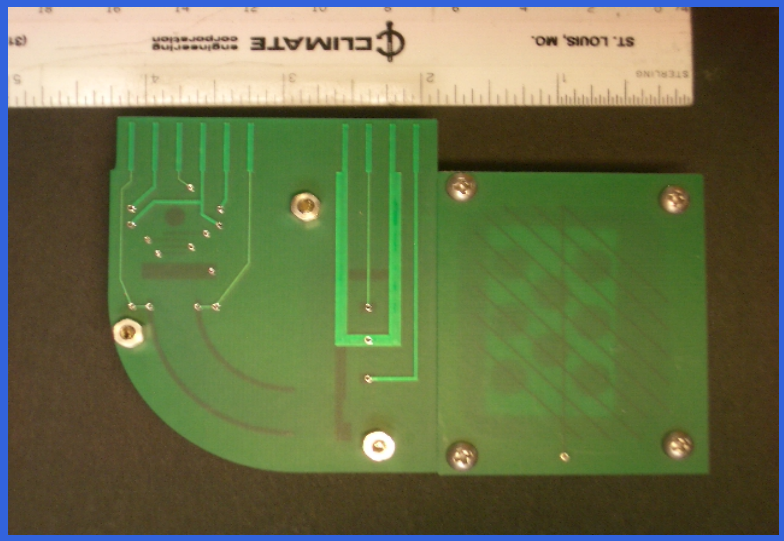


Film resistors replace discrete elements

End plates moved farther from ion path

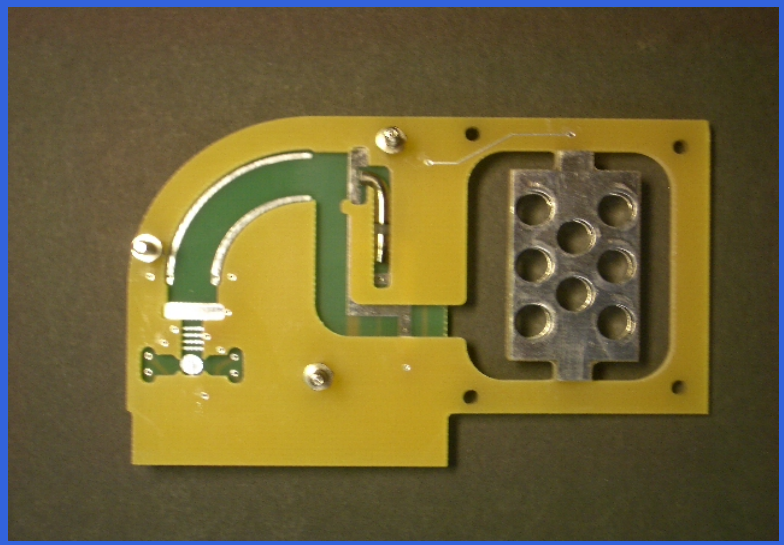
End plates can be eliminated!

Next Generation Unibody Sensor



Unibody fiberglass sensor made from FR4 plates, sandwiched together, and sealed, to form the sensor housing and vacuum chamber.

Edge connector for control electronics and ion signal.



Internal components with photolithographic elements and ion pump anode.

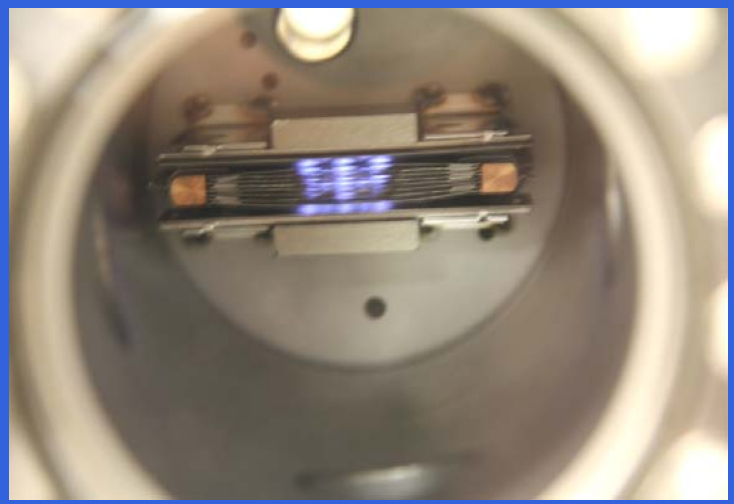
Why Sorption Vacuum Pumps?

- Drastically reduce size, weight, power consumption
- Integration into sensor enclosure eliminates the vacuum chamber
- Ion pump (IP) and non-evaporable getter (NEG) are complementary: NEG absorbs most gases; IP absorbs argon.
- Ideal for low-duty-cycle gas flow applications
- Very inexpensive: disposable
- Ion pump serves as a high vacuum gauge

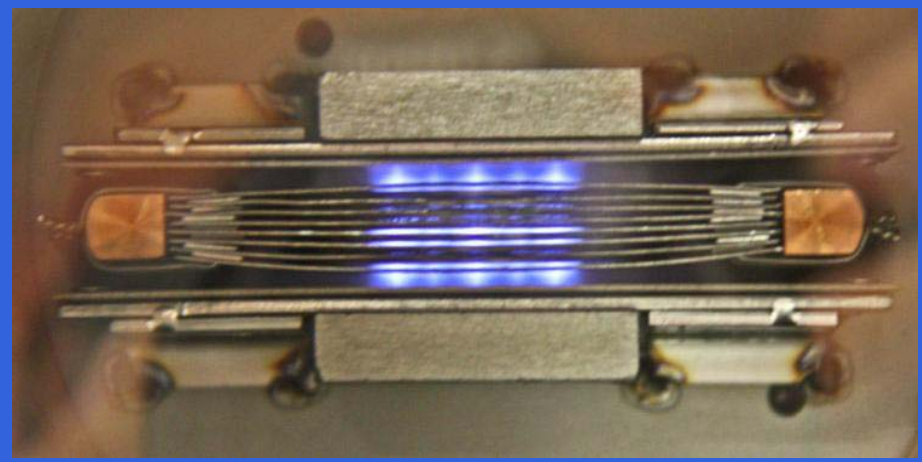
Discrete Element Ion Pumps

Varian single-cell ion pump

Multi-cell custom IP prototype

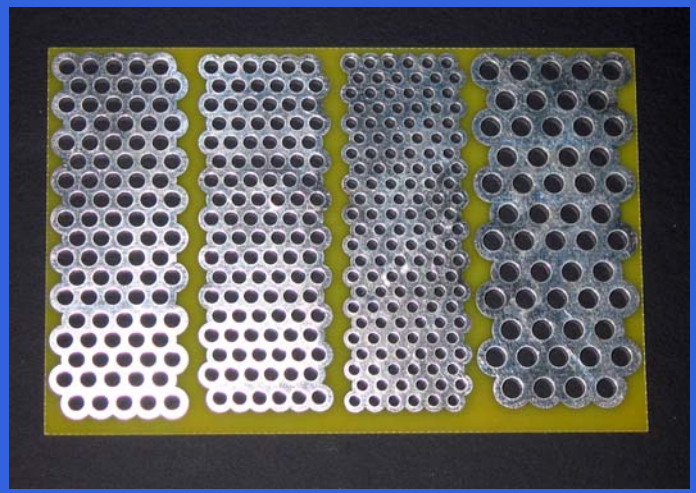


IP with NEG multi-cell anode in vac chamber

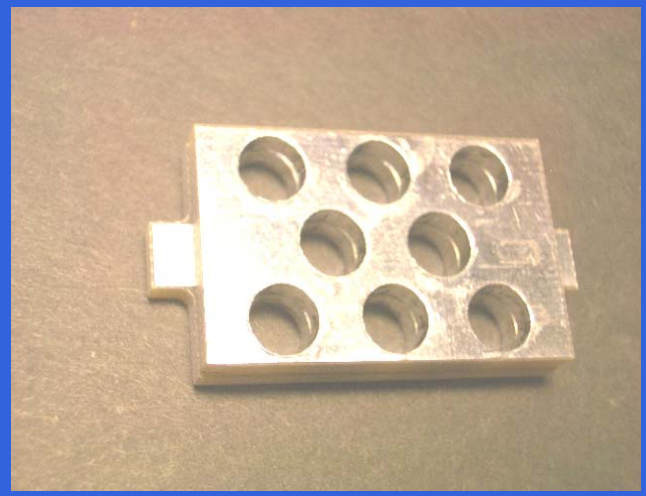


IP-NEG detail

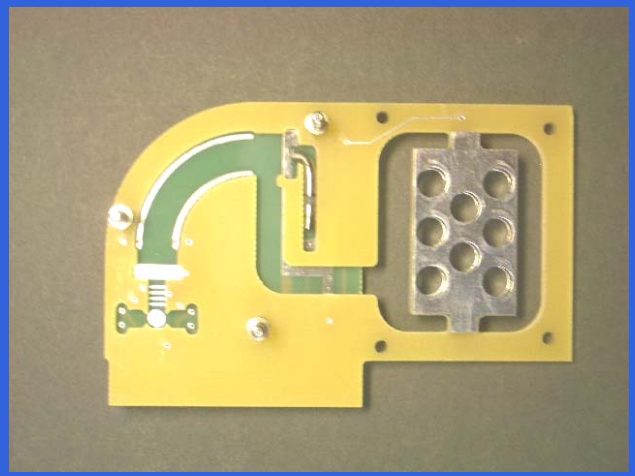
Photolithographic Ion Pump



Multi-cell anodes from vias



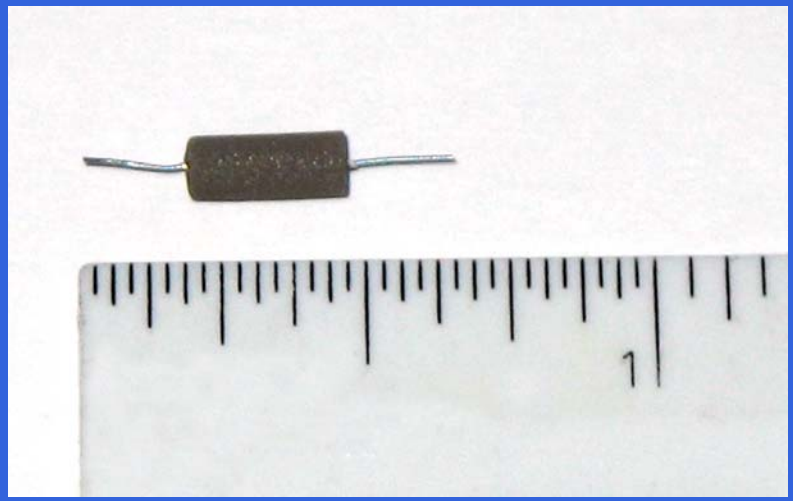
Laminated multi-cell anode



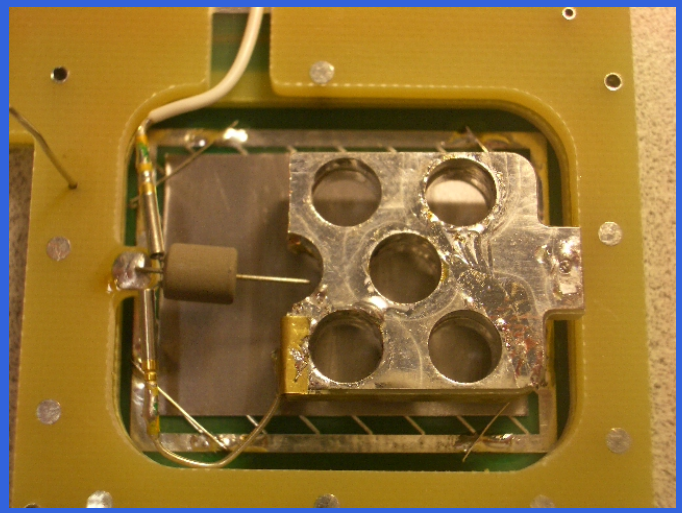
Anode mounted in sensor

Epoxy-sealed prototype

Integrated NEG and IP



SAES axial lead NEG

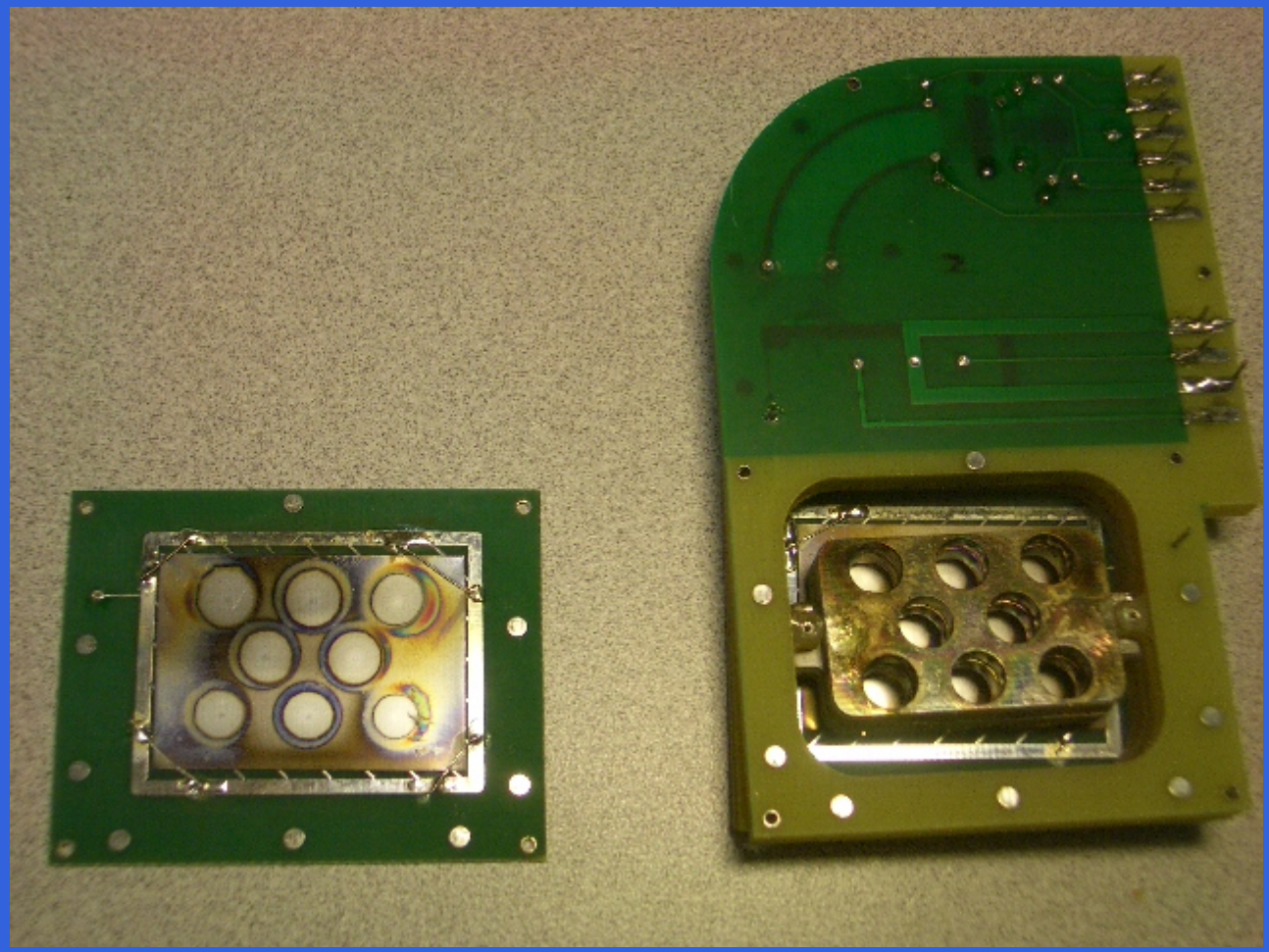


NEG and IP inside sensor

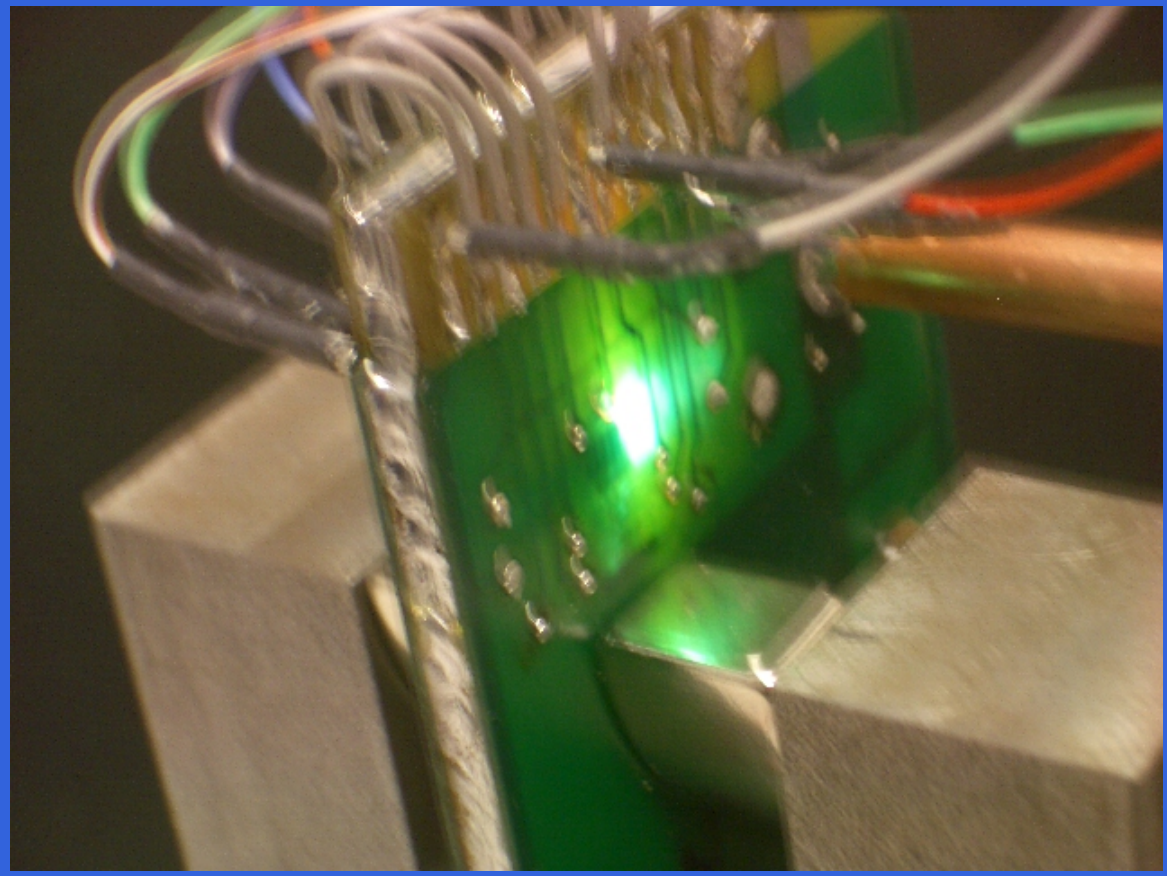
Tantalum cathode pitting

Discrete IP/NEG vacuum pump

Internal Ion Pump

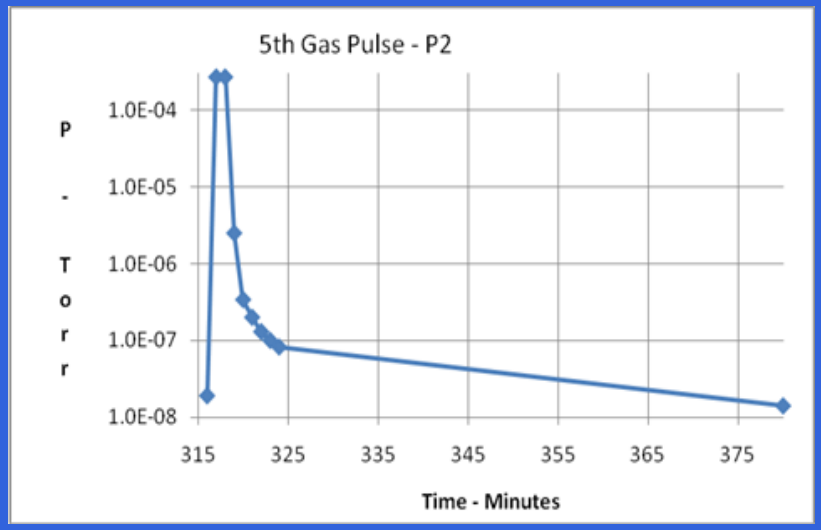


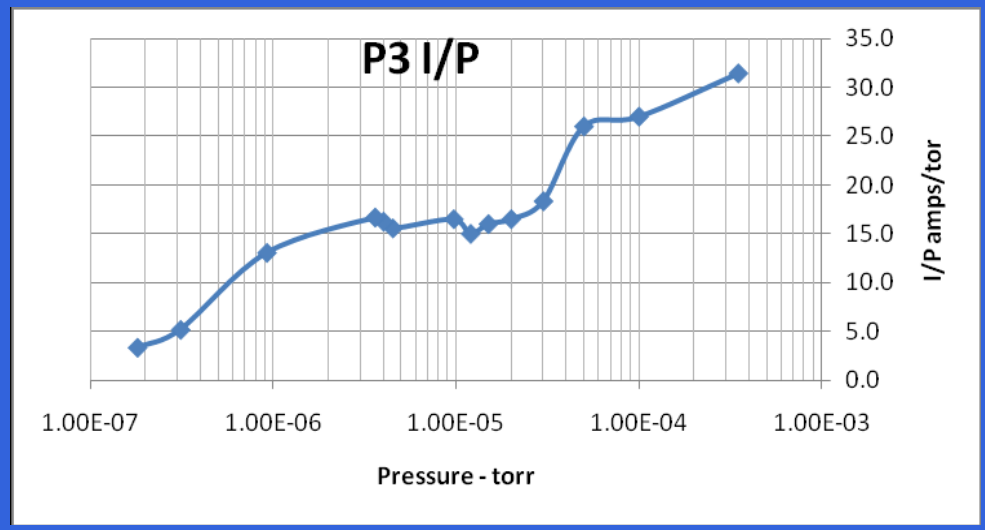
Stand-Alone Operation

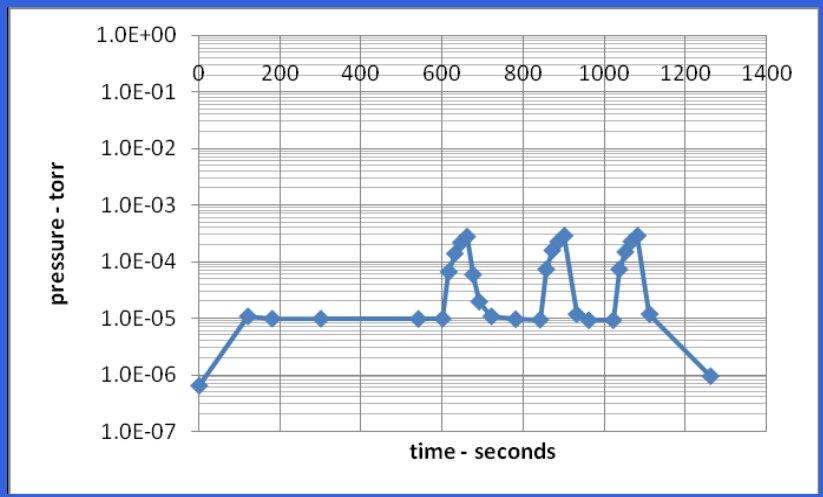


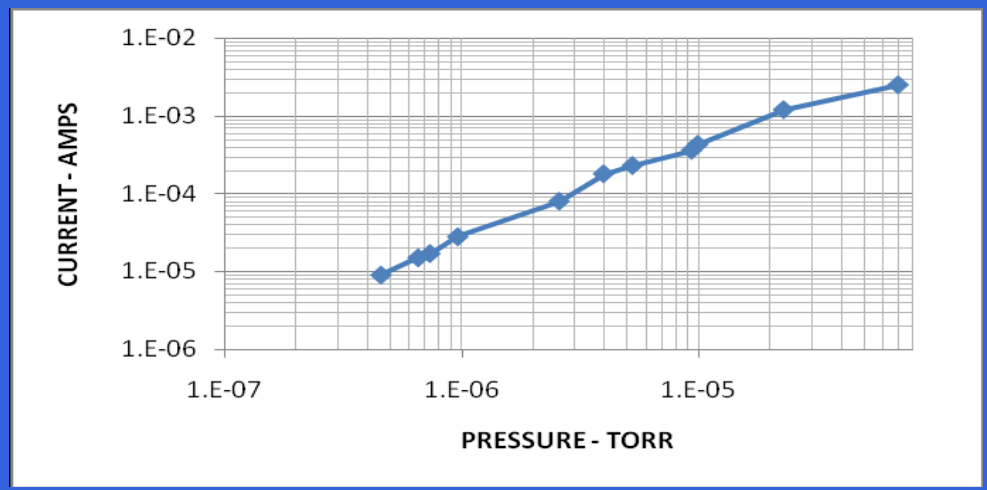
Fully-Outboard Operation—Without Vacuum Chamber!

Pumping Characteristics

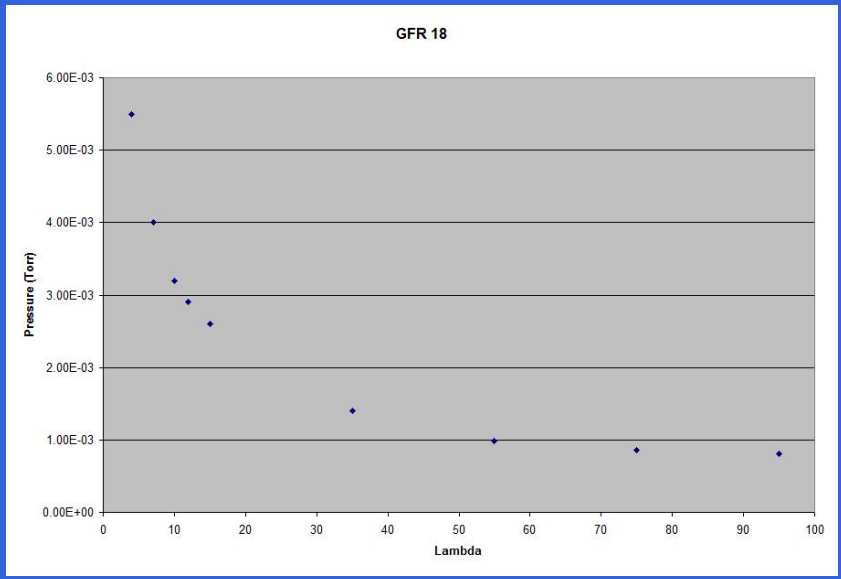


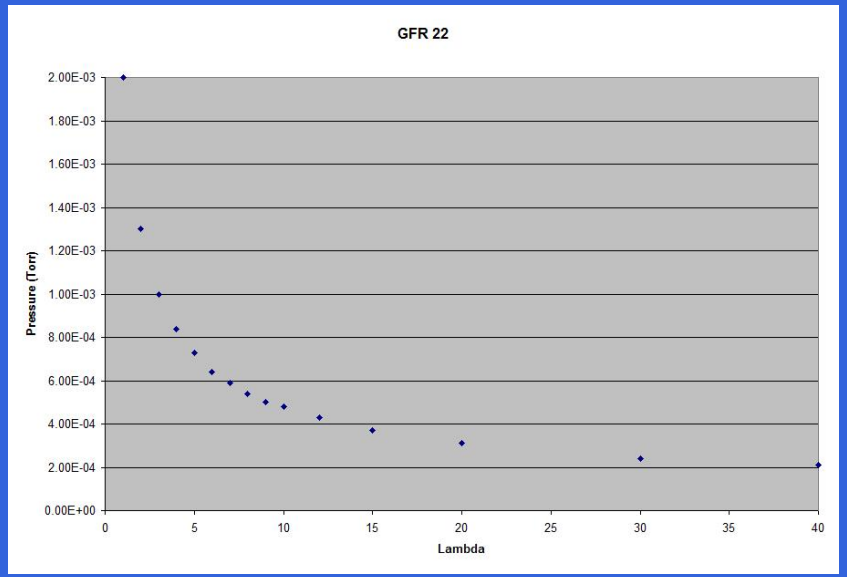


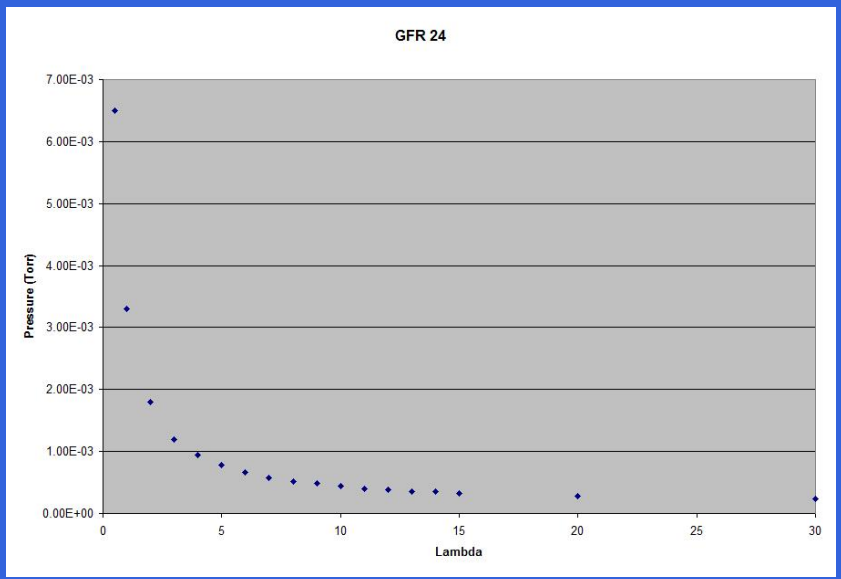


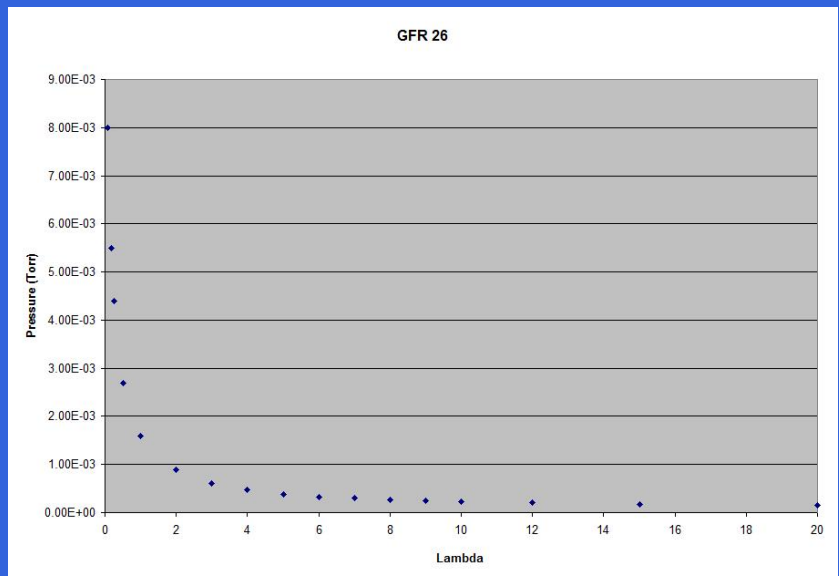


Gas Flow Restrictors









Patented Features

- Double-focusing mass spec in integrated package
- Device housing that doubles as vacuum chamber
- Photolithographic ion source and analyzer elements
- Simplified, continuous resistive-film electric-sector
- Accommodates integrated getter and ion pumps
- Quick-disconnect card-edge electronics connection
- Scalable geometry to accommodate any mass range

US Patents 6,590,207 and 6,831,276 "Microscale Mass Spectrometric Chemical-Gas Sensor"

Discrete-Element *vs.* Unibody

Discrete-Element

- machined elements
- manual assembly
- manual precision alignment
- uniformity varies
- needs vacuum chamber
- needs ext. vacuum pumps
- periodic cleaning required
- relatively fixed unit cost

– Mfg. cost: $1400 in 100's

Unibody

- integrated elements
- robotic assembly
- auto-alignment
- highly uniform
- *is* the vacuum chamber
- integrated ion pump & getter
- replace disposable sensors
- cost drops with quantity

– Mfg. cost: ~$150 in 100's

Detection of Industrial Gases

air
acetone
ammonia
argon
benzene
carbon dioxide
carbon monoxide
disilane
boron trifluoride
ethanol
ethylene oxide
Freon 134A
helium
hexane
hydrazine
hydrofluoric acid
hydrogen
hydrogen chloride
hydrogen sulfide
isopropyl alcohol
methane
methanol
nitric oxide
nitrogen dioxide
nitrogen fluoride
nitrous oxide
oxygen
phosphine
silane
sulfur dioxide
water

(mass >50 amu)

Scalability

- Mass range and resolution scale with sensor central radius:

R_0	Mass range	M/ΔM
10 mm	1-50 amu	45
20 mm	6-150 amu	130
30 mm	~10-300 amu	~280

- Resolution determined only by analyzer radius and slit width
- Same electronics and power supplies can operate all sensor sizes
- Software control/data capture independent of sensor size

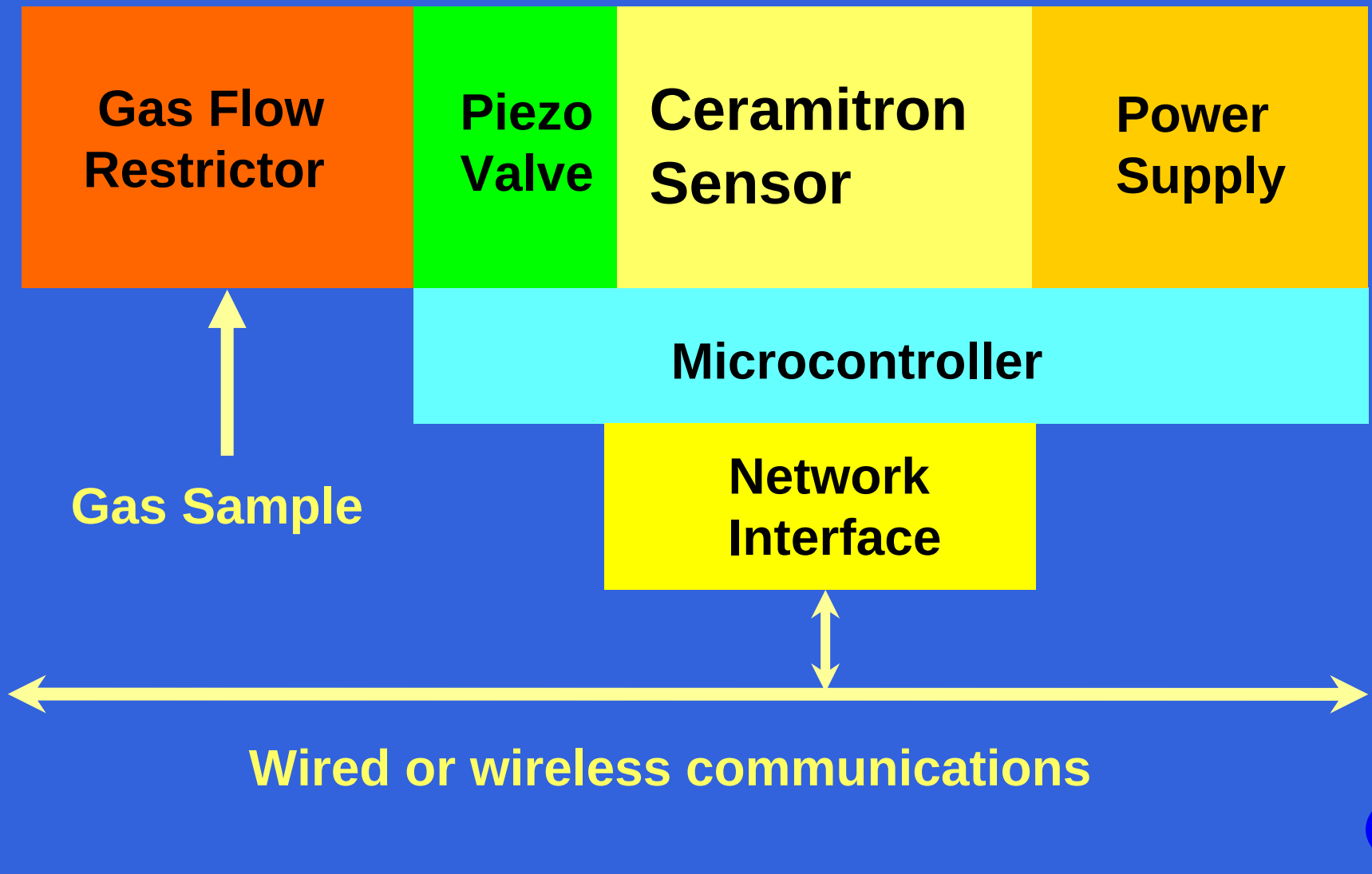
Low-Duty-Cycle Applications for Ceramitron Sensors

- Remote sensors for unmanned platforms
- Greenhouse gas monitoring
- Environmental air quality monitoring
  - Landfills, HVAC in buildings, spacecraft, submarines
- Weather balloons: atmospheric depth profiling
- Worker safety/industrial hygiene/early fire detection
- Process streams and down-hole monitoring
- Battlefield standoff detectors

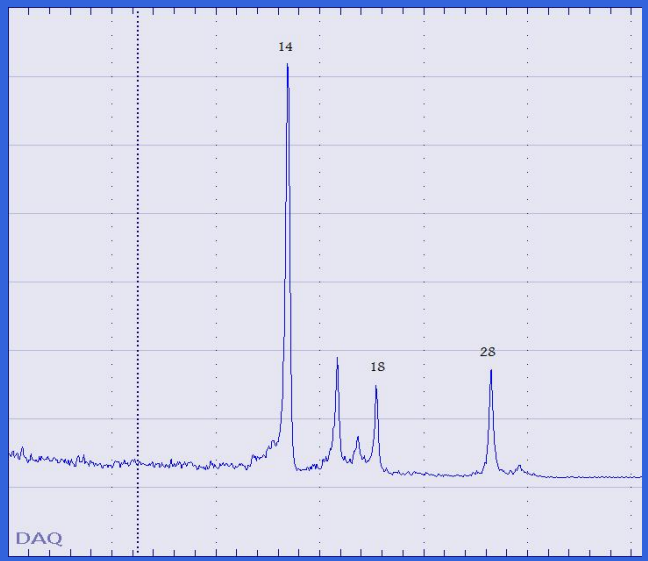
Benefits of Integrated Sensors

- Ceramitron's patented sensors can provide attractive price, performance advantages, improved reliability
- The unibody design improves profit margins by significantly lowering manufacturing & total life-cycle costs
- Photographically scaling the size of the sensor optimizes mass range and resolution to target applications
- Multigas sensing versatility, and intrinsically low cost, allow OEMs to address a wide range of applications in their target markets.

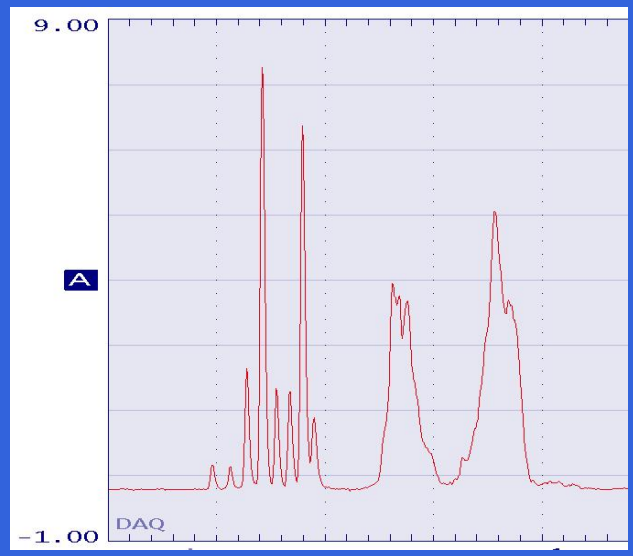
Typical Sensor Node



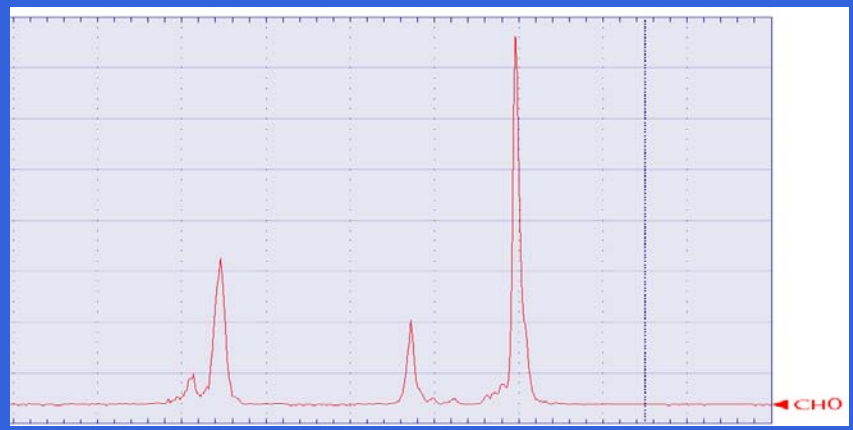
Miscellaneous Mass Spectra



Nitrogen in air



Isopropanol in air



Krypton m/z=84 in air

Acknowledgements

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