Rigid and Flex PCB based Microsystems For Mobility, Systems Development and Harsh Environments

David Fries

Stan Ivanov, Geran Barton,

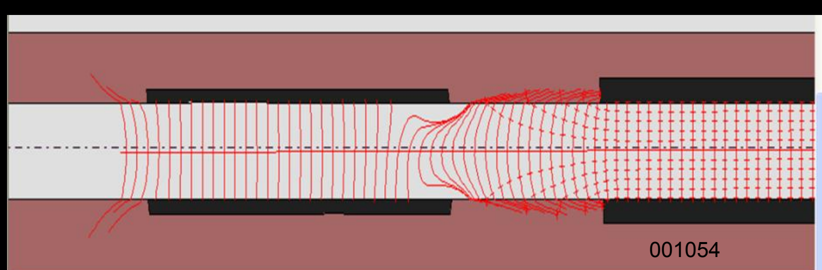
Heather Broadbent- USF Marine Sci

Tom Weller USF- Engineering

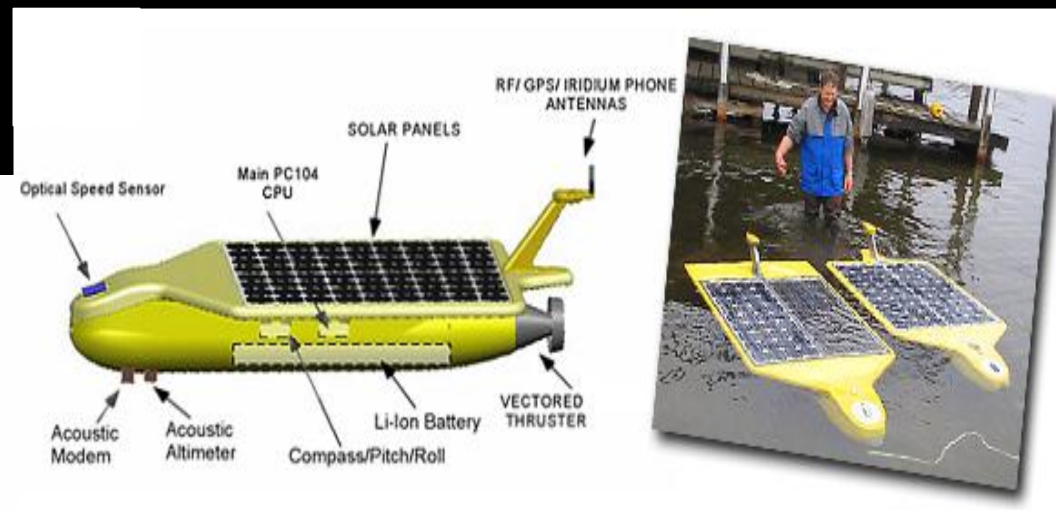
Erkinjon Nazarov- Draper Labs

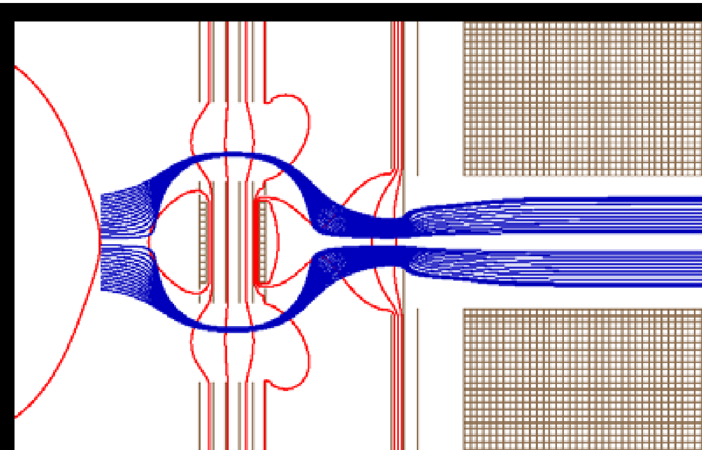
Ross Willoughby- Chem Space

Franco Lodato-Motorola Mobility



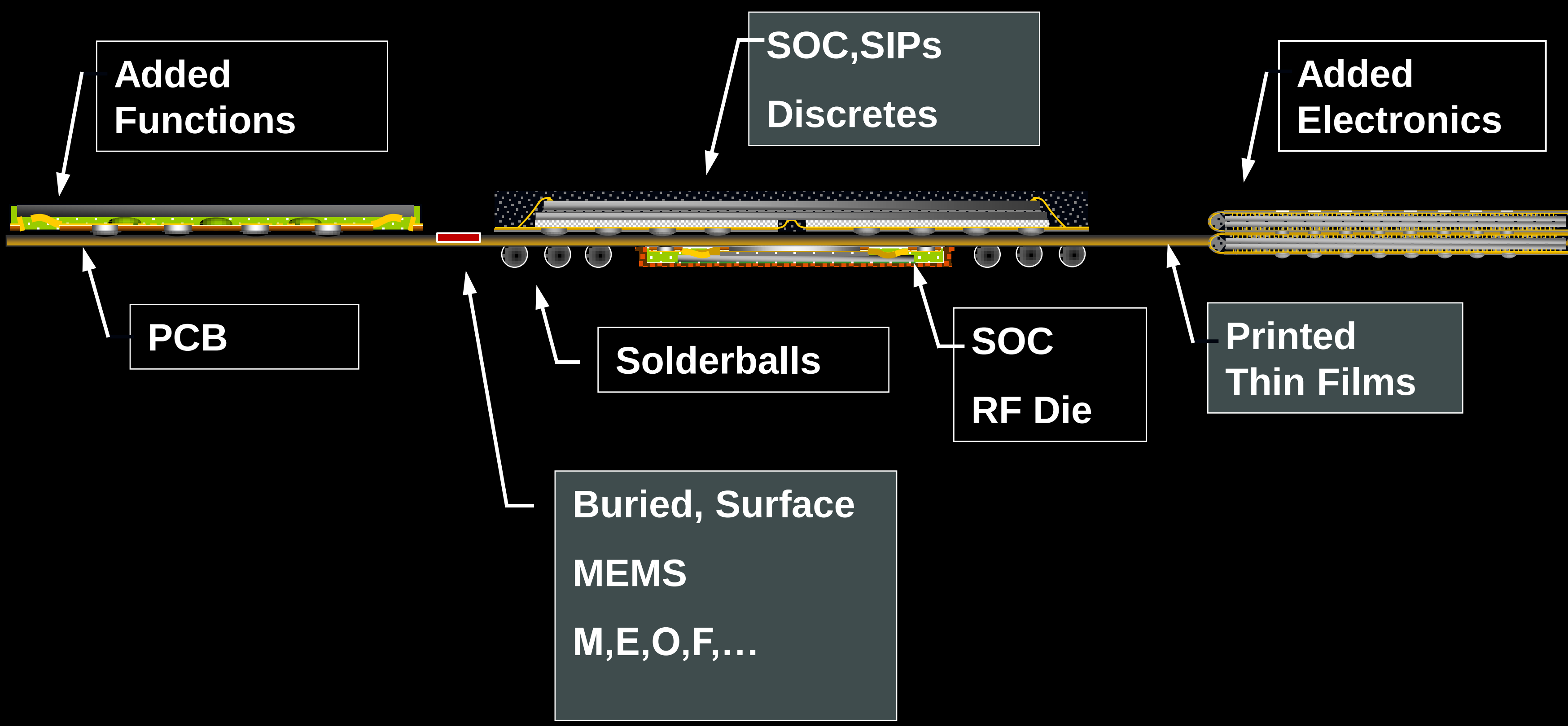
Flex PCB/ PCBMEMS Research Area
Mobile Sensors and Mobility Robotics/Automation





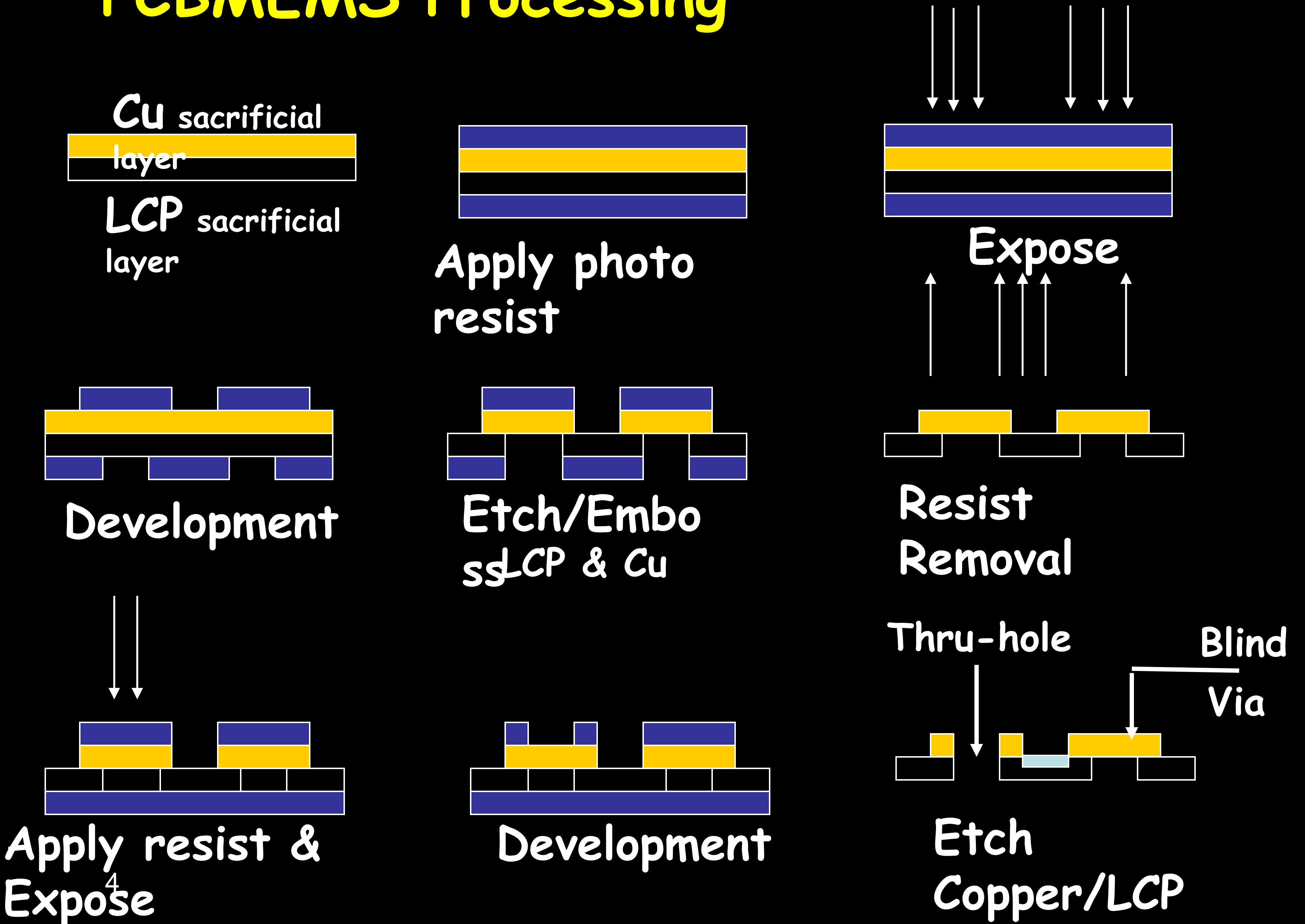
PCBMEM Systems (Organic, Polymer-MEMS)

PCBMEMS: The combined insertion of mechanical, fluidic, optical and electronic functions into the PCB landscape, which permits a complex "system on a board".



ML^2

PCBMEMS Processing



Process flow for PCB Power Cell structures

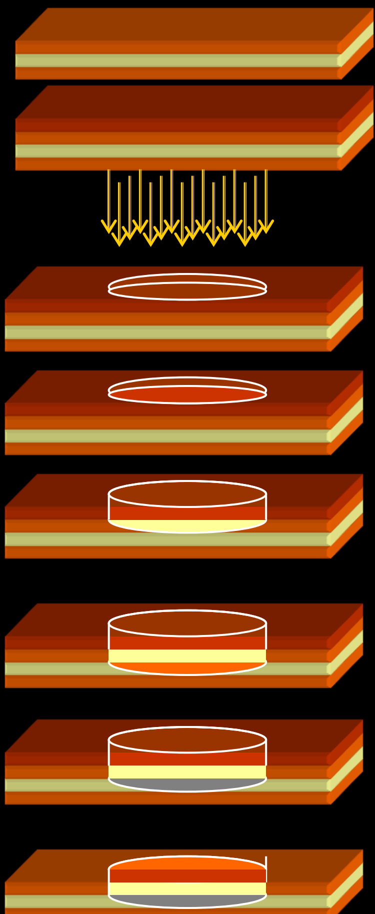


Photo-resist spinning and baking

Photo-resist exposure

Photo-resist development

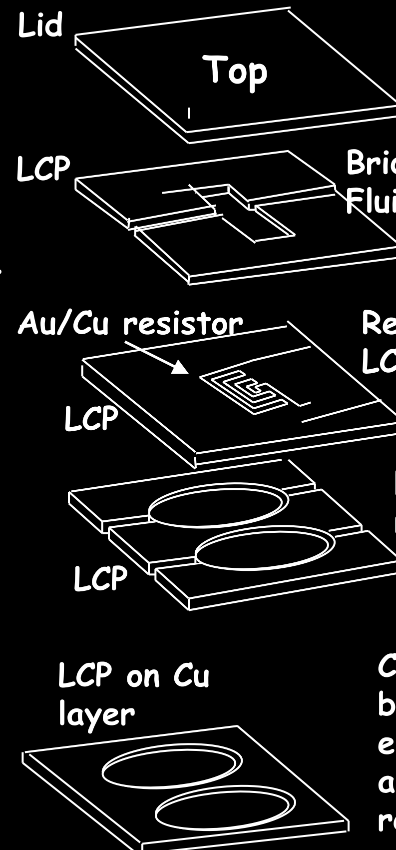
Copper Etching

LCP material Etching

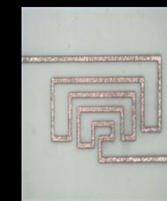
Metals plating

Photo-resist washing

Stacking of the Layers



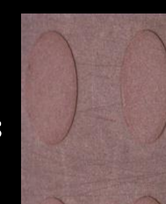
Micro-pictures



Au/Cu resistor on LCP substrate

Filling electrolyte reservoirs, LCP materials

Electrolyte reservoirs



Cu cathode

Zn on Cu anode

Integration, & Bonding

Polyimide Layer by Layer Process Flow

Positive-Tone Photoresist

HD Microsystems HD8000

Spin coating

↓

Drying step

↓

Expose

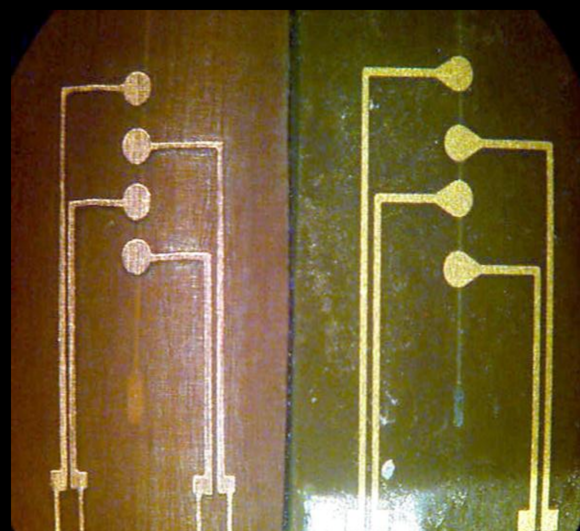
↓

Develop

Shipley 453

↓

Cure



Cu electrode and embedded micro-fluidic channel in polyimide.

Negative-Tone Photoresist

HD Microsystems PI 2771

Spin coating

↓

Drying step

↓

Expose

↓

Post Exposure Bake

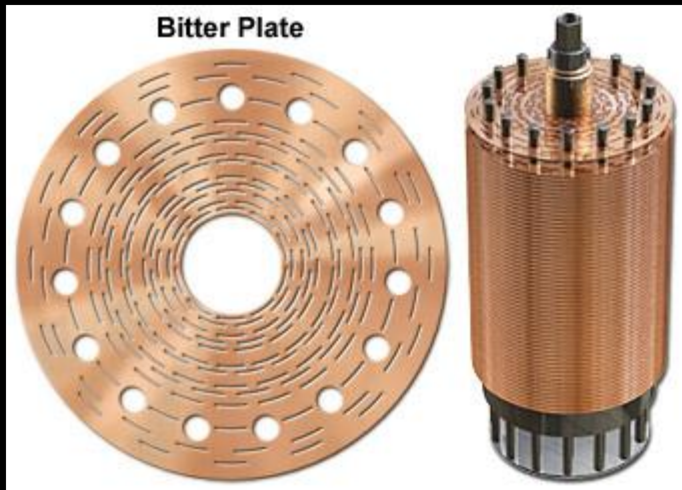
↓

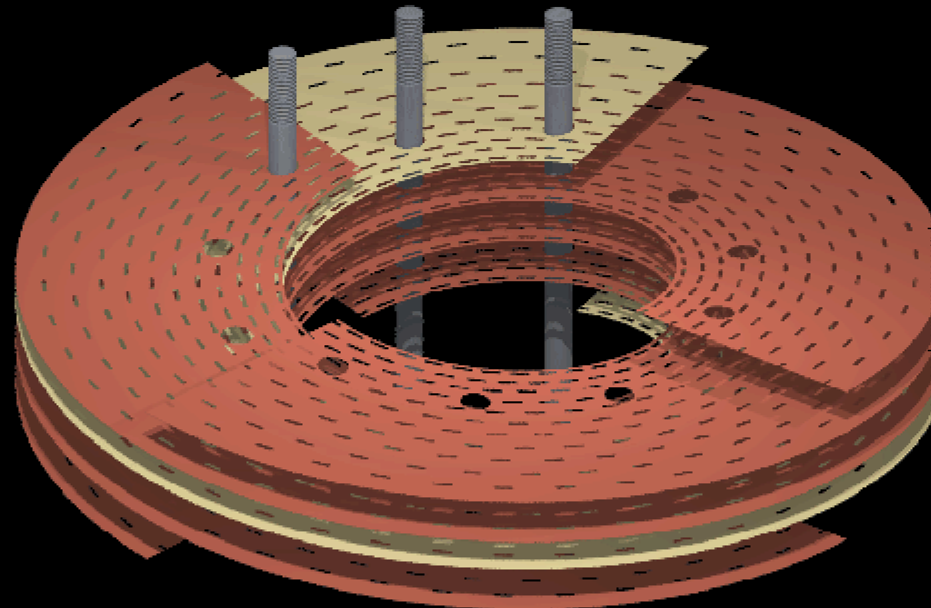
Develop

Shipley 453

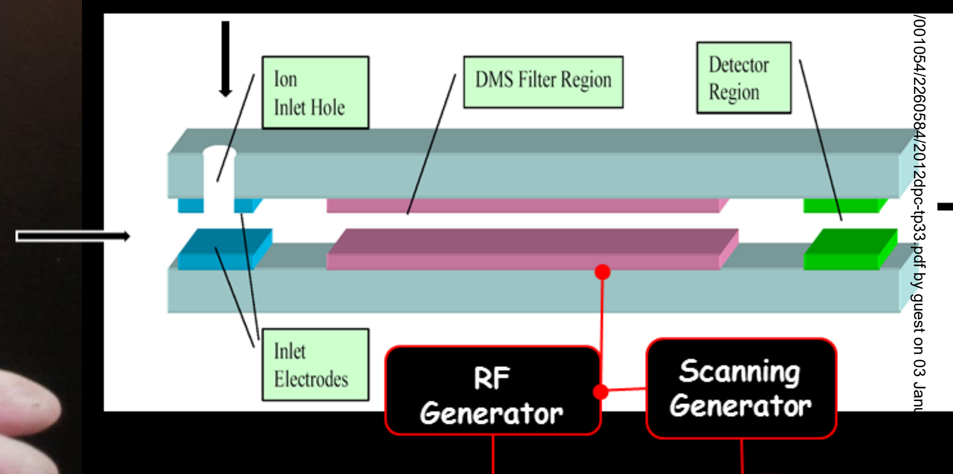
↓

Cure





Microfluidics by Stacking and Spacing

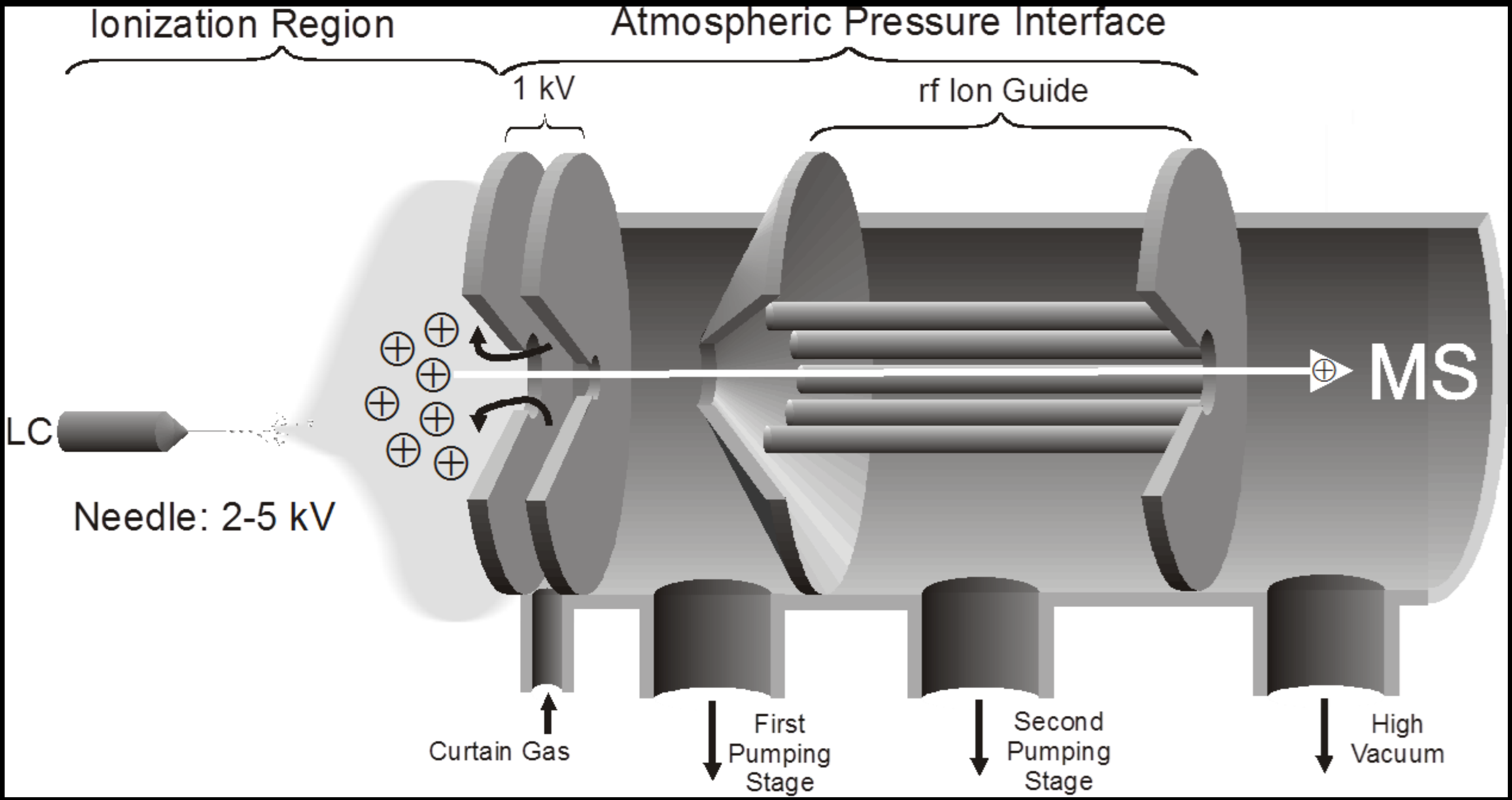


Microscale Application

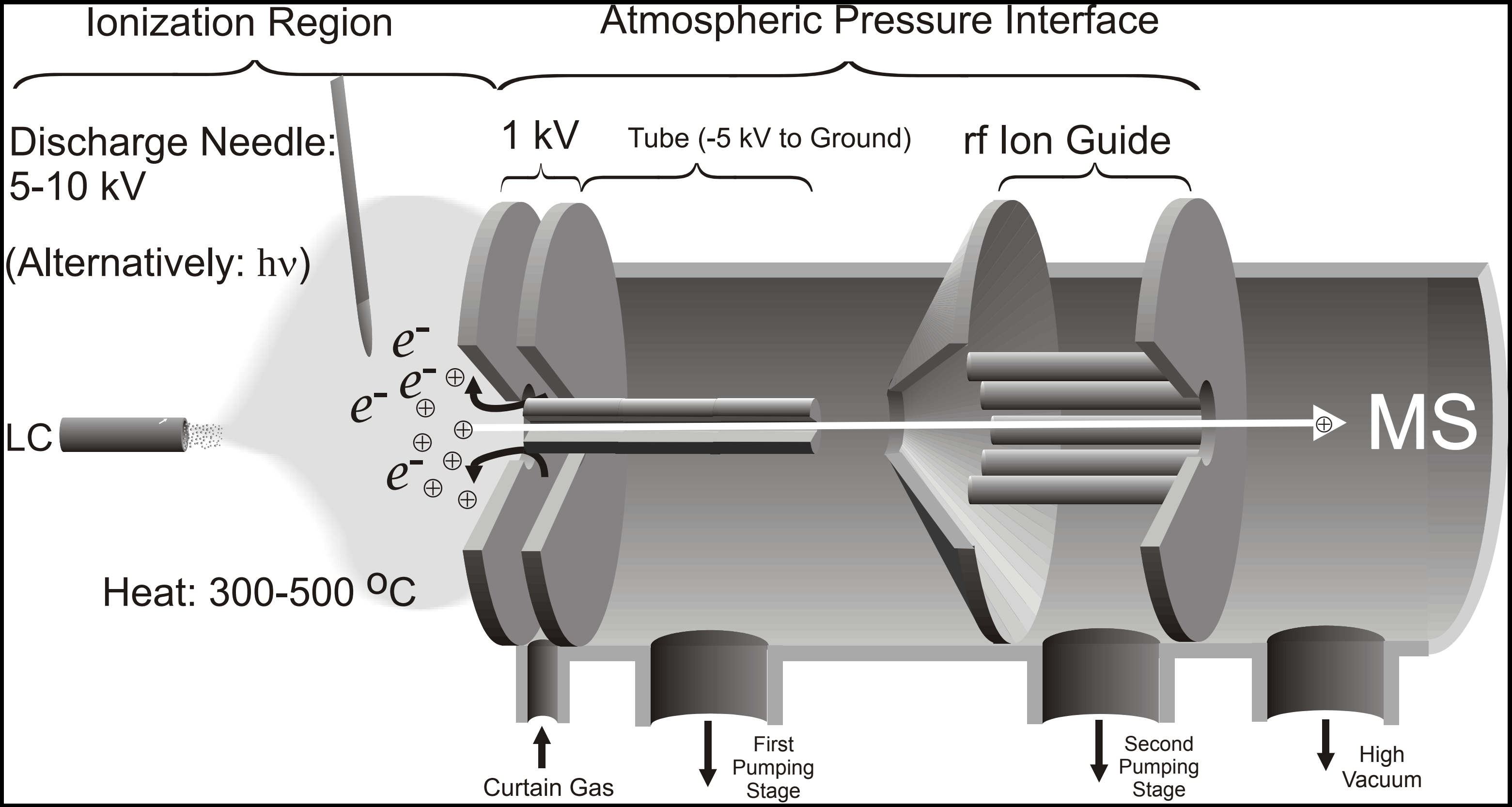
Atmospheric Sources

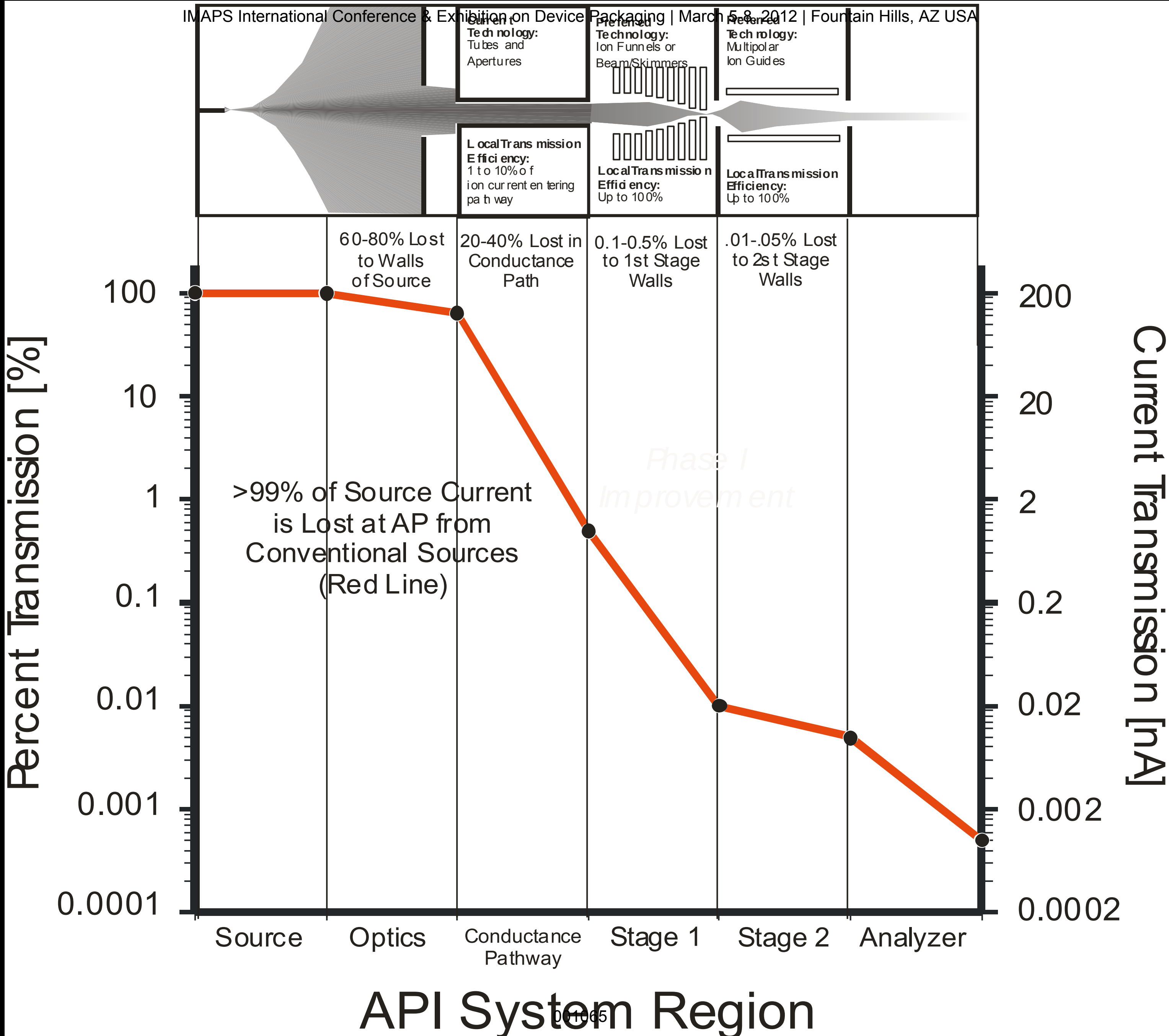
- Within the traditional mass spec instrumentation field there is ongoing interest in new atmospheric ion source designs for more effective and versatile ion generation.
- We have been exploring ion optical elements for atmospheric ion sources to facilitate and control the transport of ions through the interface region between atmospheric sources and the vacuum region of a mass analyzer. This is our vacuum miniaturization strategy.
- The ion optical elements are used to increase the focusing of ions from the atmospheric ion generators into a very small differential pumping aperture at the interface of the vacuum system, exponential reduction in the gas load and decreases the need for power hungry high throughput vacuum pumping solutions.
- How to create controlled, efficient ion transport from atmospheric pressure to vacuum pressure to enable a continuous sampling portable mass spectrometer systems?

Electrospray

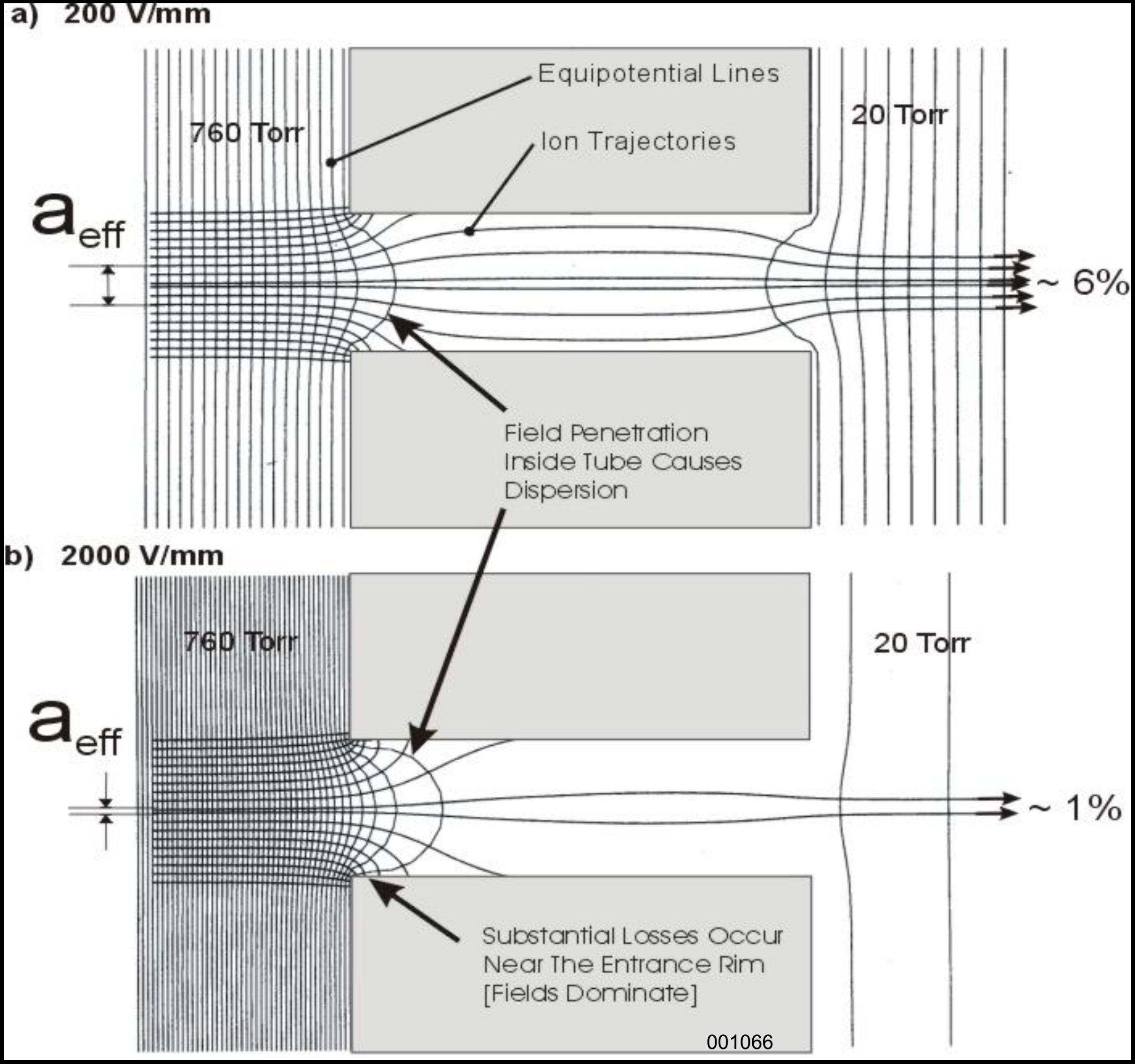


APCI


Ionization Region
Atmospheric Pressure Interface
Discharge Needle:
5-10 kV
(Alternatively: hν)
1 kV
Tube (-5 kV to Ground)
rf Ion Guide
LC
e-
MS
Heat: 300-500 °C
Curtain Gas
First
Pumping
Stage
Second
Pumping
Stage
High
Vacuum

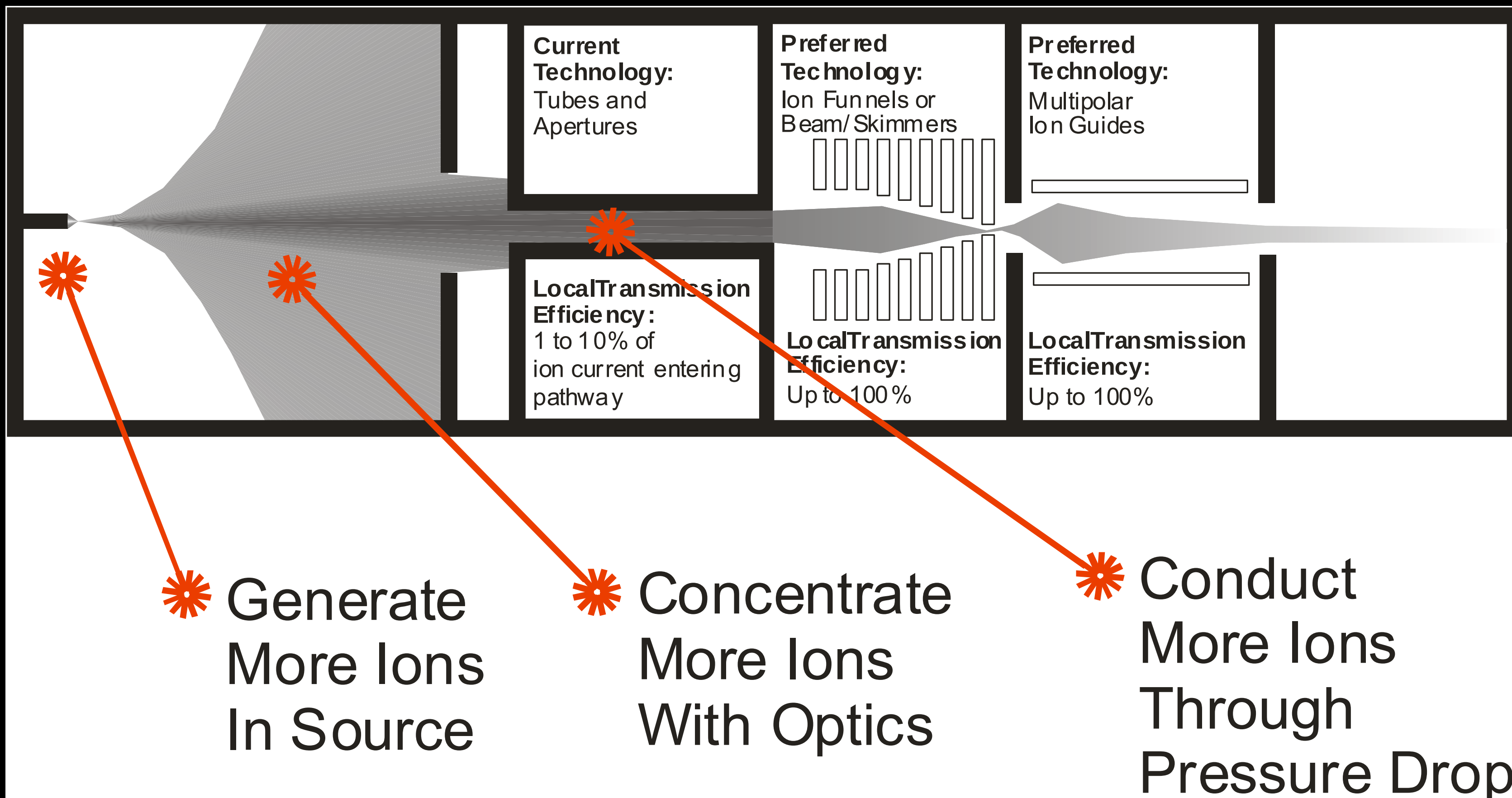

Current Technology: Tubes and Apertures
Local Transmission Efficiency: 1 to 10% of ion current entering pathway
Preferred Technology: Ion Funnels or Beam/Skimmers
Local Transmission Efficiency: Up to 100%
Preferred Technology: Multipolar Ion Guides
Local Transmission Efficiency: Up to 100%
60-80% Lost to Walls of Source
20-40% Lost in Conductance Path
0.1-0.5% Lost to 1st Stage Walls
.01-.05% Lost to 2st Stage Walls
>99% of Source Current is Lost at AP from Conventional Sources (Red Line)
Percent Transmission [%]
100
10
1
0.1
0.01
0.001
0.0001
Current Transmission [nA]
200
20
2
0.2
0.02
0.002
0.0002
Source
Optics
Conductance Pathway
Stage 1
Stage 2
Analyzer
API System Region

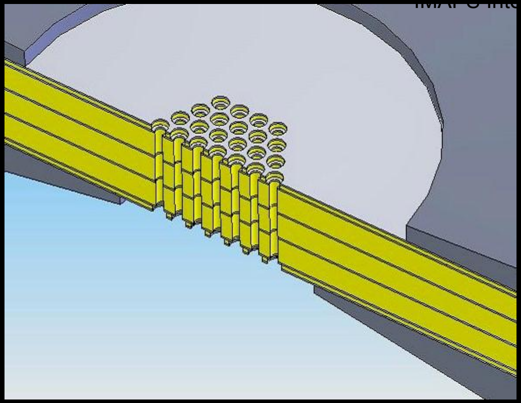
Ions are lost at the conductance opening



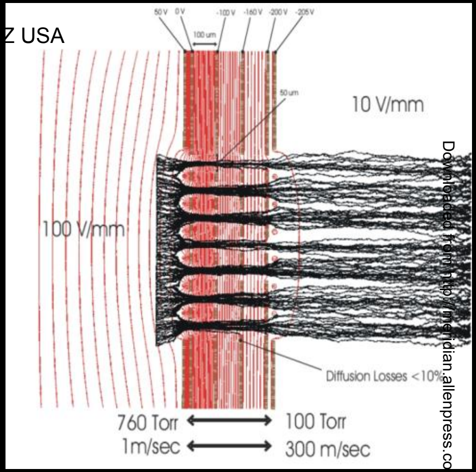
Conventional conductance pathways select against ions .

How can your improve sensitivity?





Apply Multilayer PCBMEMS/ PCB Microfluidics



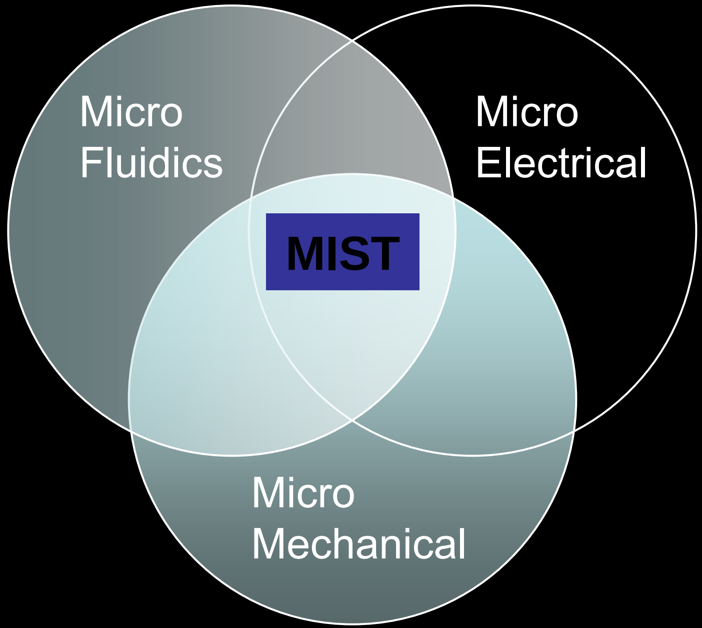
- Need flexible microfabrication technologies to generate atmospheric pressure ion optical devices.
- Need novel materials, processes, and designs for micro ion optical systems for control of ions within sources, and across apertures and conductance arrays.
- Patterned microstructures and geometries for flow and electrostatic field shaping using PCB-MEMS

PCB MEMS leads to MIST

- Micro Ion-Optical Systems Technology [MIST] is the convergence of *fluidic-electrostatic–mechanical* functions into an active or passive system for ion manipulation and control using controlled, shaped electric fields and controlled fluidics.

- The system may be a system in package (SIP)

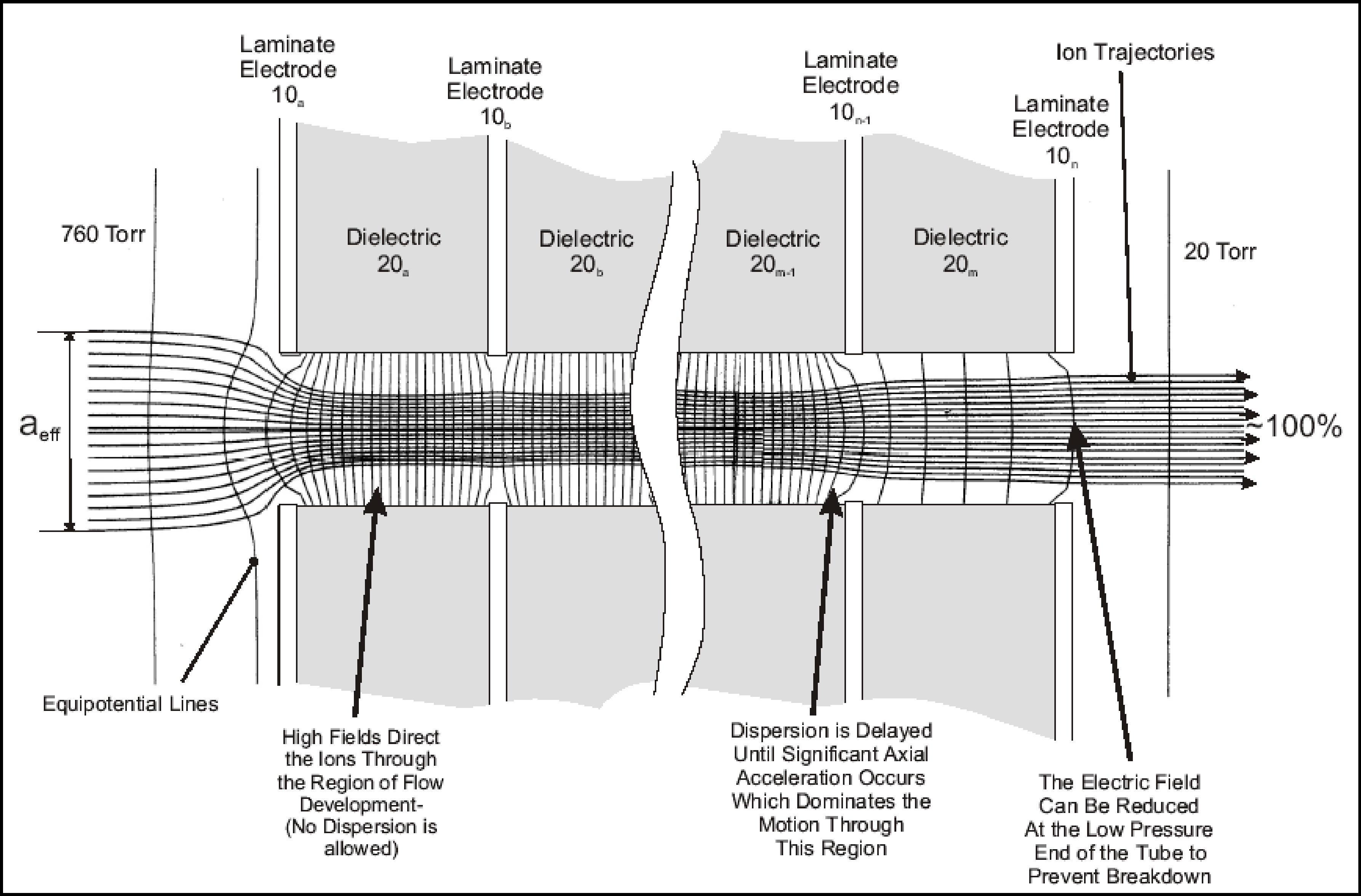
- Active systems may dynamically control fields and flow and contain moving mechanical components. Passive systems have no moving parts.



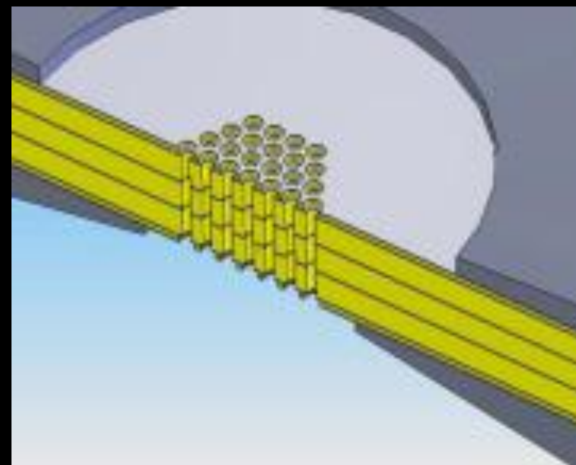
Advantages of PCBMEMS MIST

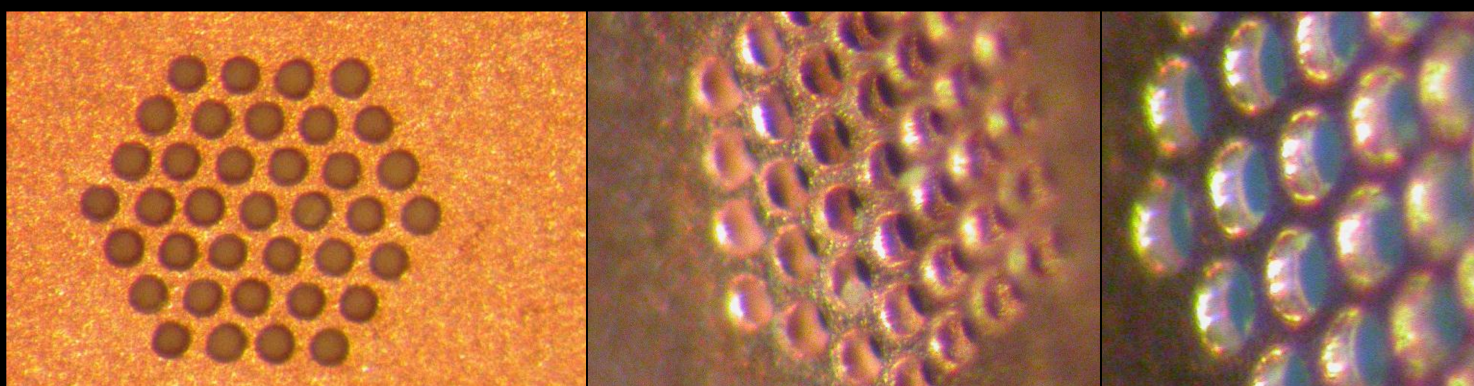
- Adaptive Sampling of Ions
- Laminated 3D Systems
- Feedback Control of Ion Transmission
- Complex, Integration of Electronics Possible
- Large Area Designs possible

Control Parameters- Flow vs Field



What worked: PCBMEMS





Left Image PCBMEMS processing of double-sided LCP/metal with 37element 70 um hole array.
Central and Right Images: Off axis view to illustrate the metal/dielectric/metal configuration

Added Field Shaping Structures -
fabricated on top of elements using the PCBMEMS process

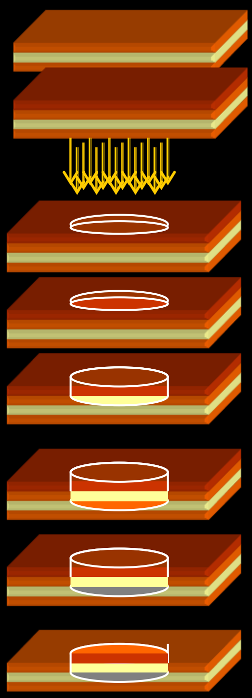


Photo-resist spinning and baking

Photo-resist exposure

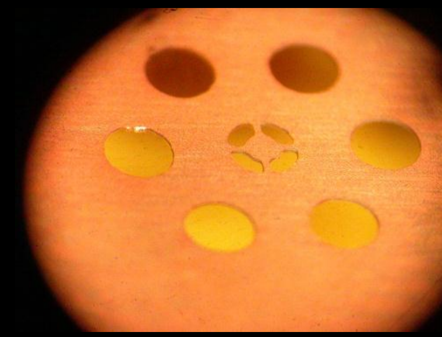
Photo-resist development

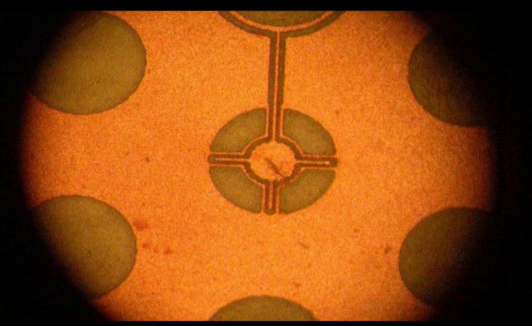
Copper Etching

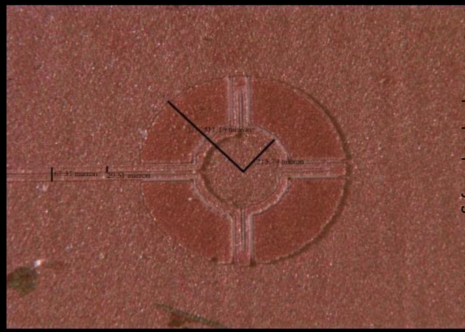
LCP material Etching

Metals plating

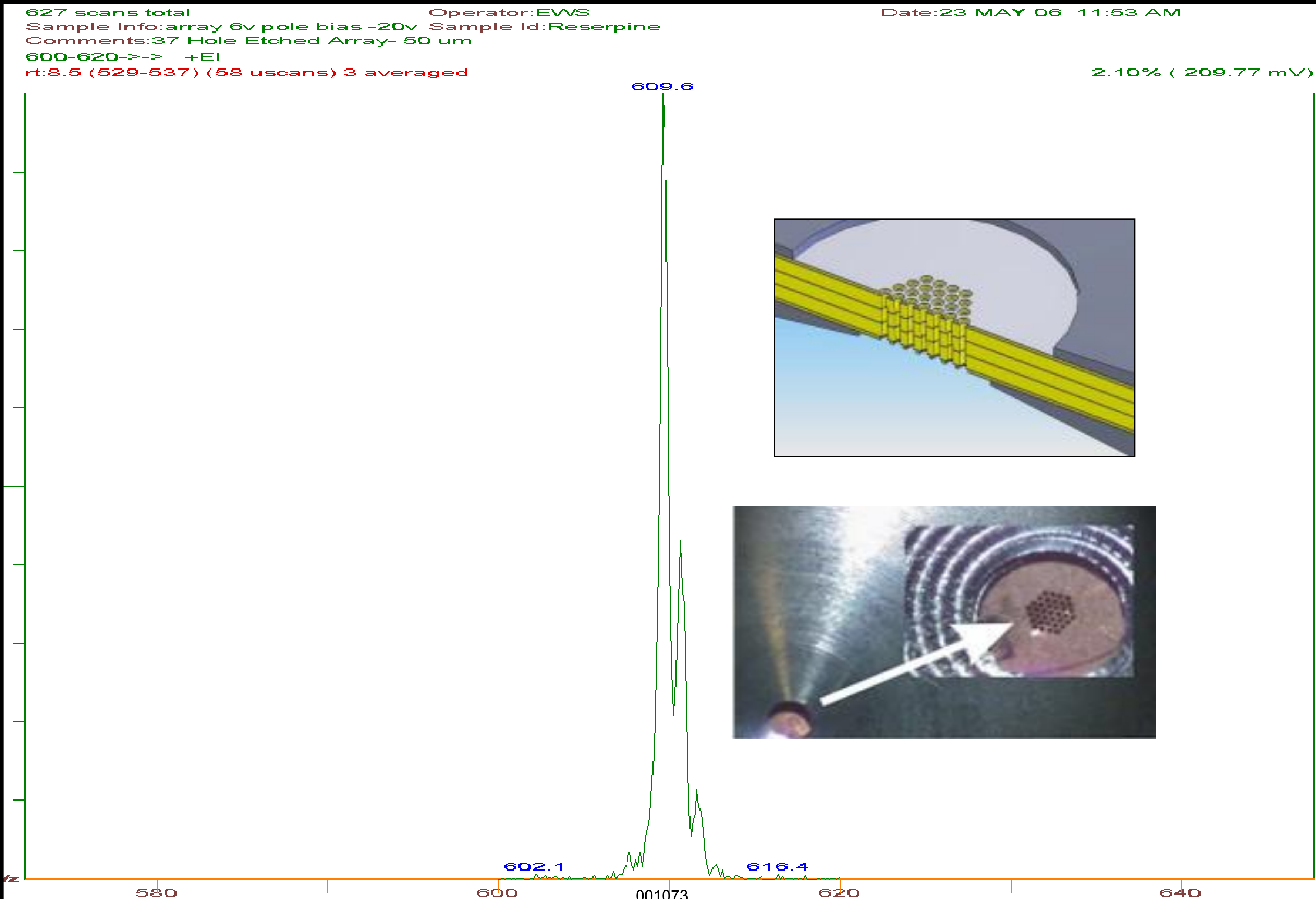
Photo-resist washing



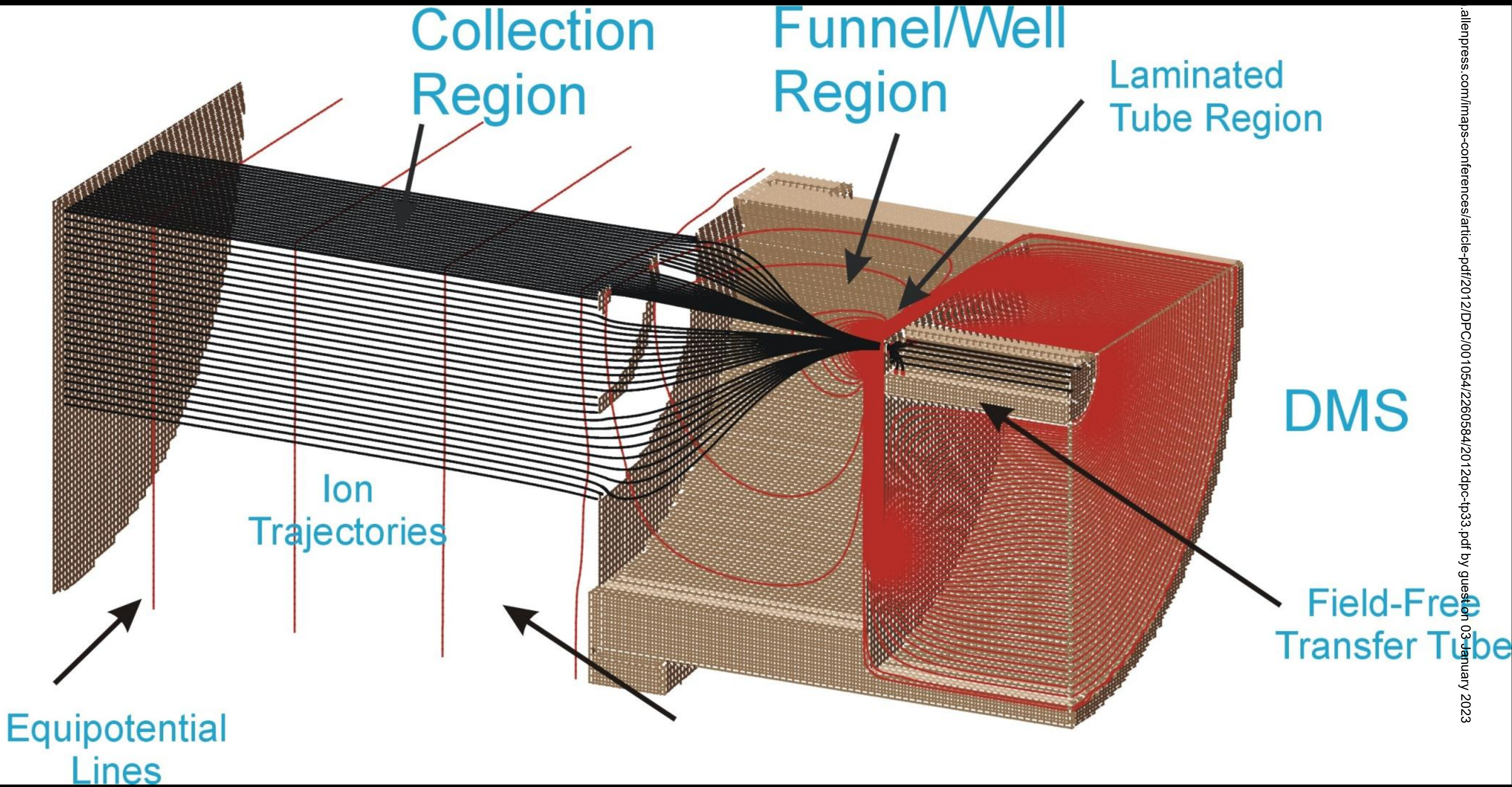




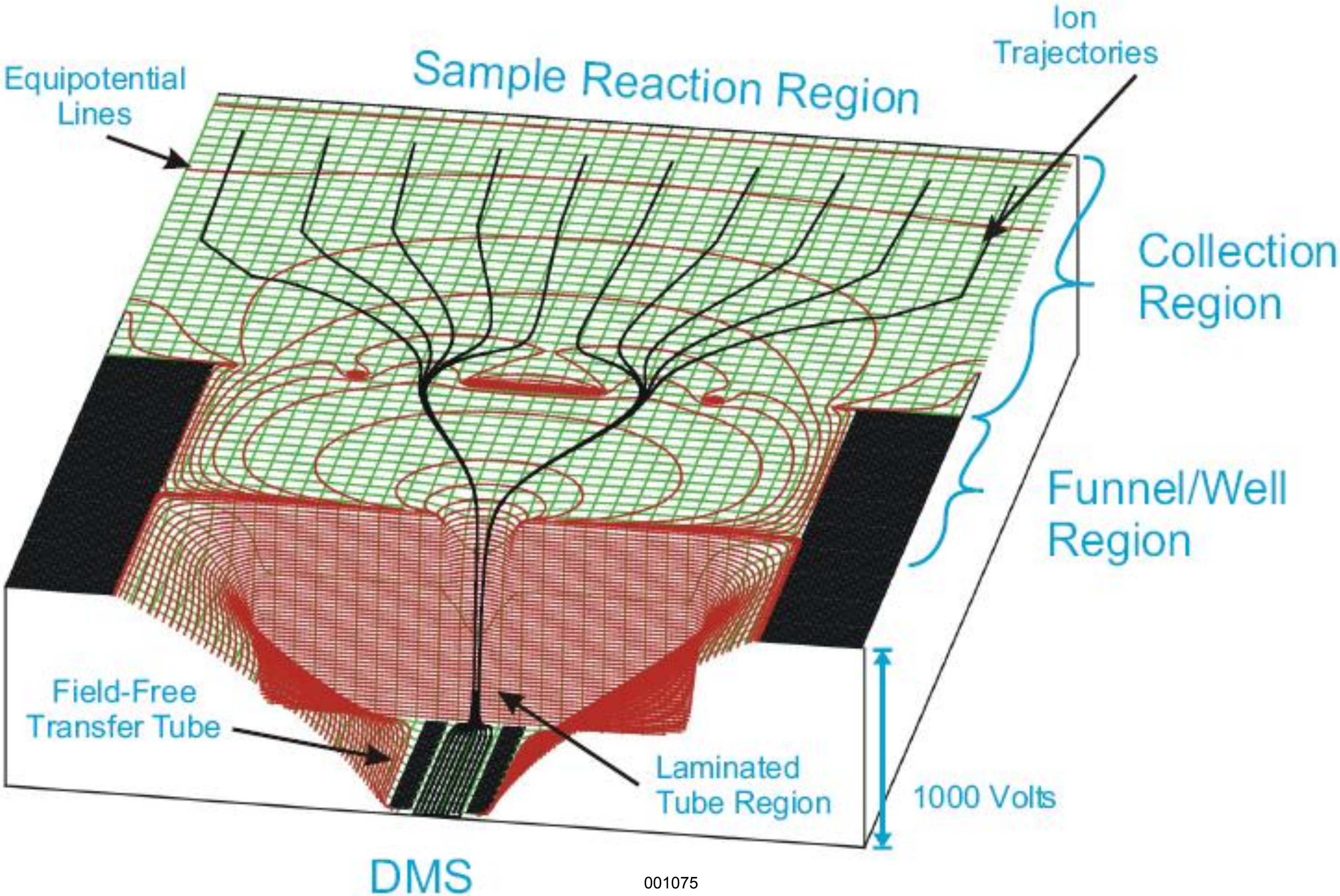
Mass spectrum of reserpine electrosprayed and focused through the multilayer aperture array



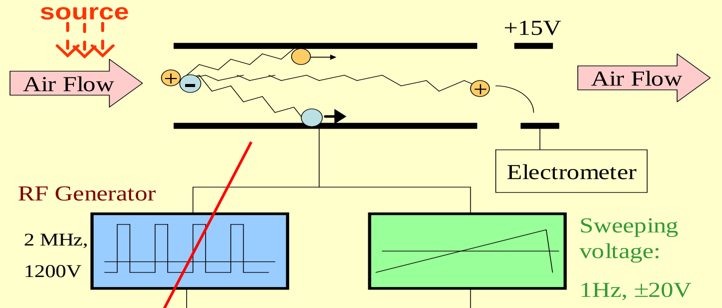
Ion Collection into DMS-MS

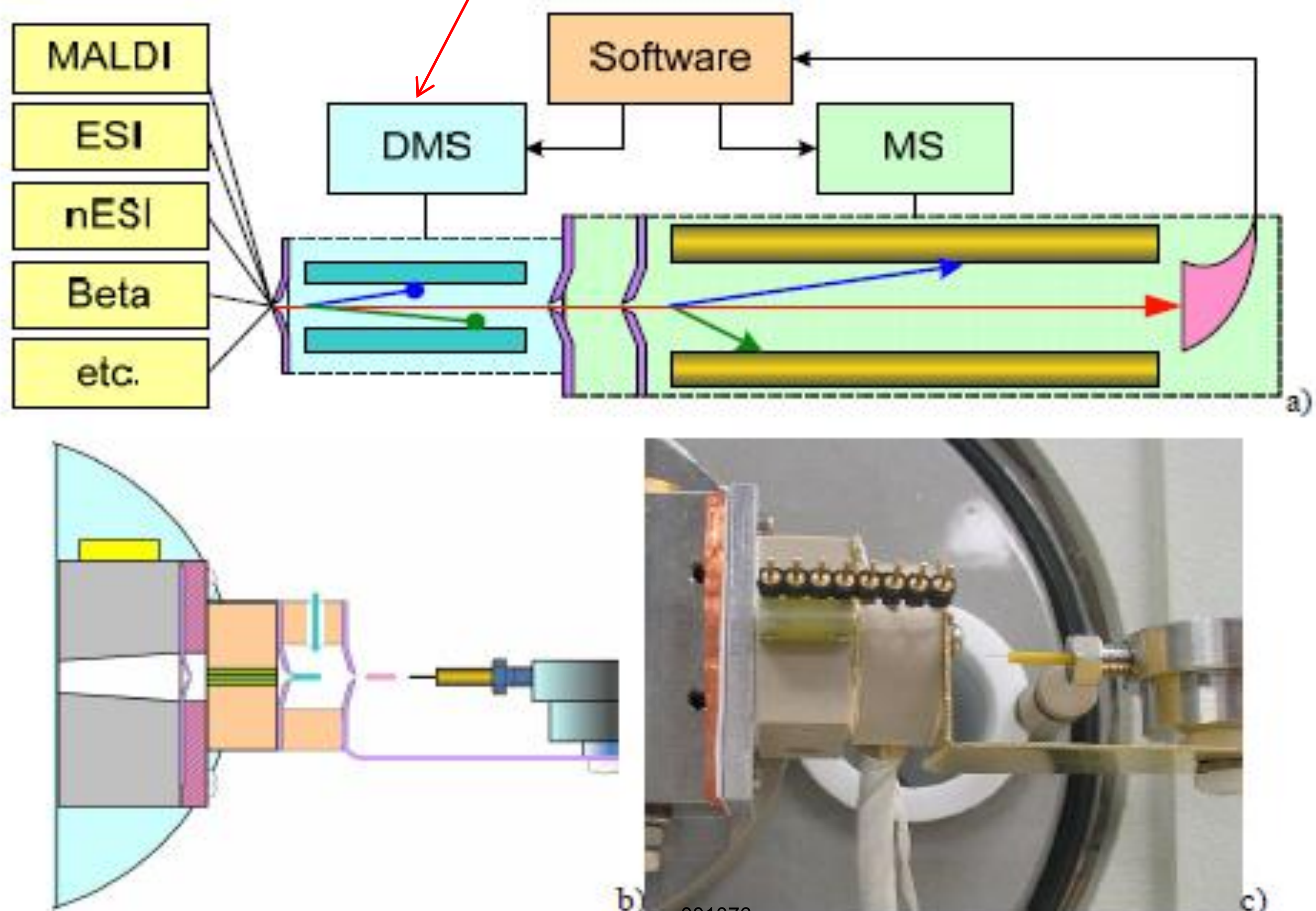


Ion Compression into DMS-MS



DMS Method for Ion Separation at Atmospheric Pressure





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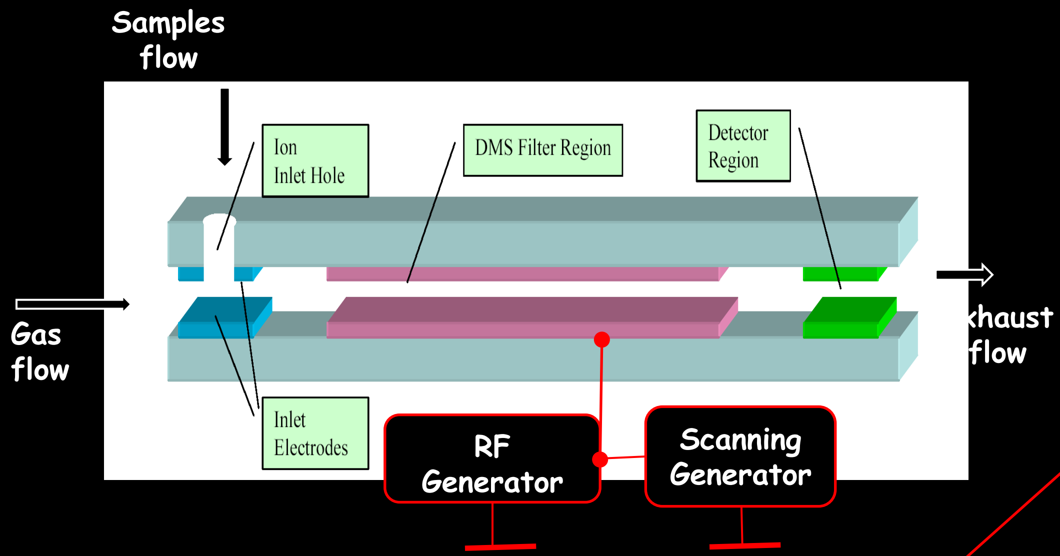
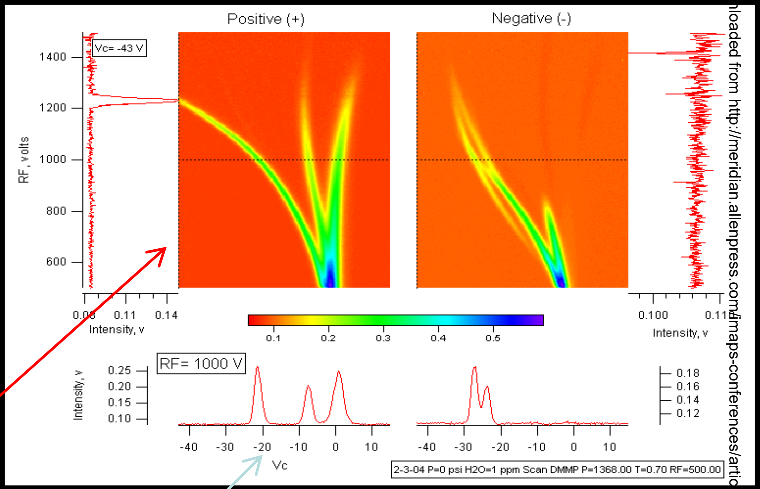
The DMS Sensor Via Spacing PCBs



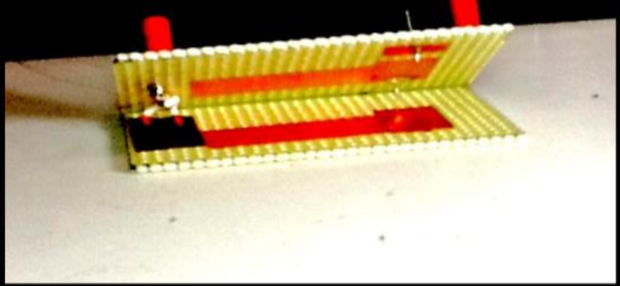


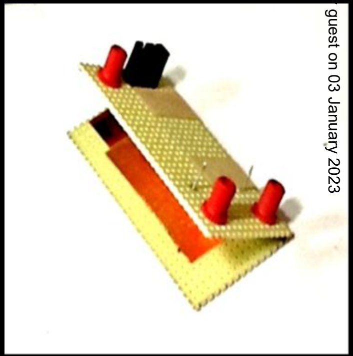
Linear Spectra – *dependence of ion current vs. scanning voltage, when RF is constant*

2D Dispersion plots – *scanning of Rf voltage and compensation voltages are synchronized*

Typical operation parameters:

- Analytical gap……,,,,,.0.5x 2x15 mm^3;
- E_{max} …………. ……….up to 30 kV/cm;
- V max……………………up to 1.5.kV;
- Frequency…………….. ……1-2 MHz;
- Transport gas flow ………0.2-1.l/min;
- Pressure ……… ……….1.5 – 0.1 atm;
- Swiping voltage ……….. -40+10 V





Method Description and Mathematical Formalism

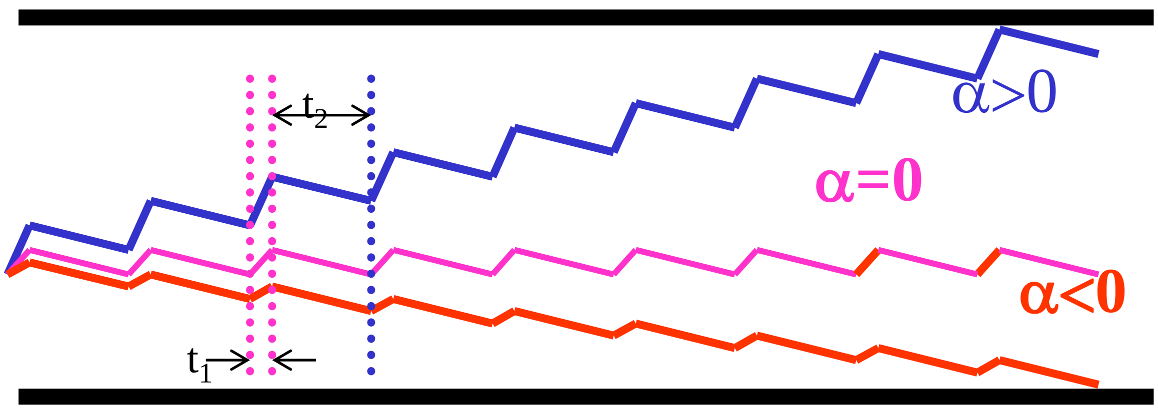
$$d\vec{r}\,/\,dt = \vec{\vartheta}_{fluid} + \langle \vec{\vartheta}_{dif}(E(t)) \rangle + K_{\perp}(t)\,[\vec{E}_{RF}(t) + \vec{E}_{c}(t)]$$

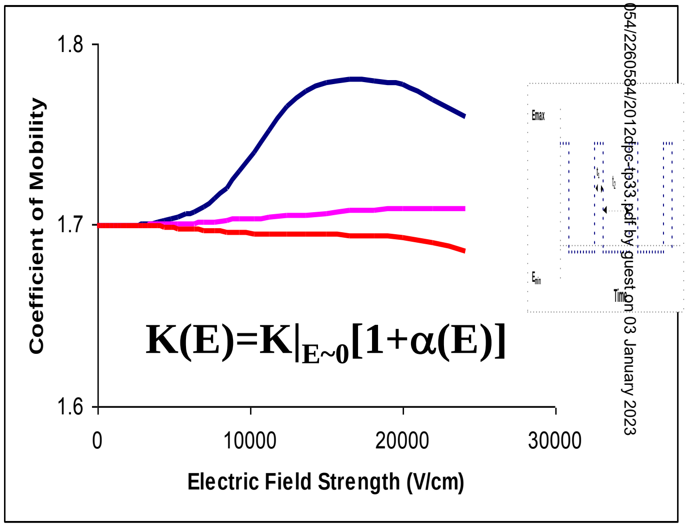
$\vec{\vartheta}_{RF}(t) = K_{\perp}(E(t) * \vec{E}_{RF}(x, y, z, t)$ - Ion movement due to effect of RF

$\vec{\vartheta}_{C}(t) = K_{\perp}(E(t) * \vec{E}_{c}(t)$ - Ion movement due to effect of V_c

$\vec{\vartheta}_{F} = \vec{\vartheta}_{fluid}(x, y, z)$ - Ion movement due to fluid dynamic

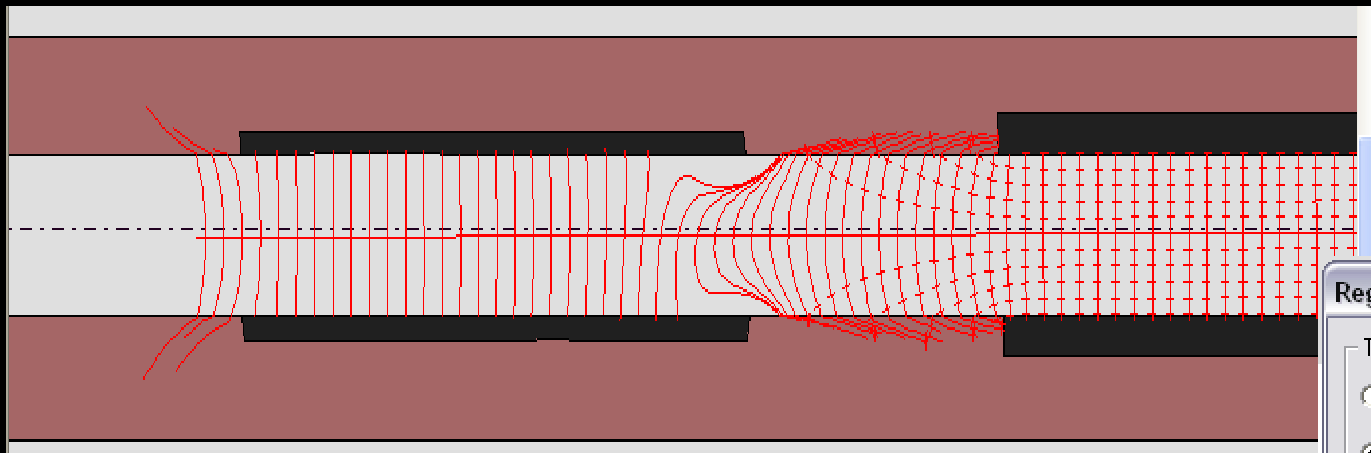
$\vec{\vartheta}_{dif} \propto \sqrt{2D / \Delta t}$ - Effective ion movement due to diffusion with random direction.

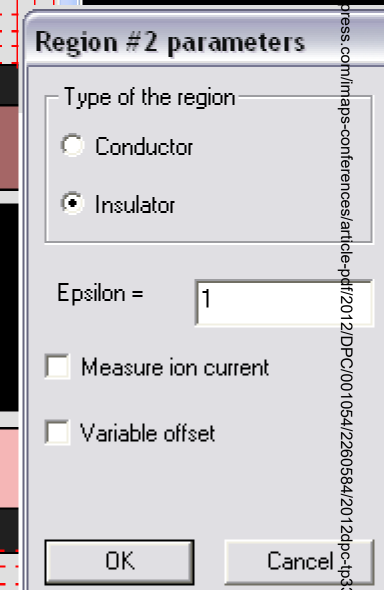




Effect of Substrate Material on Electric Field Distribution

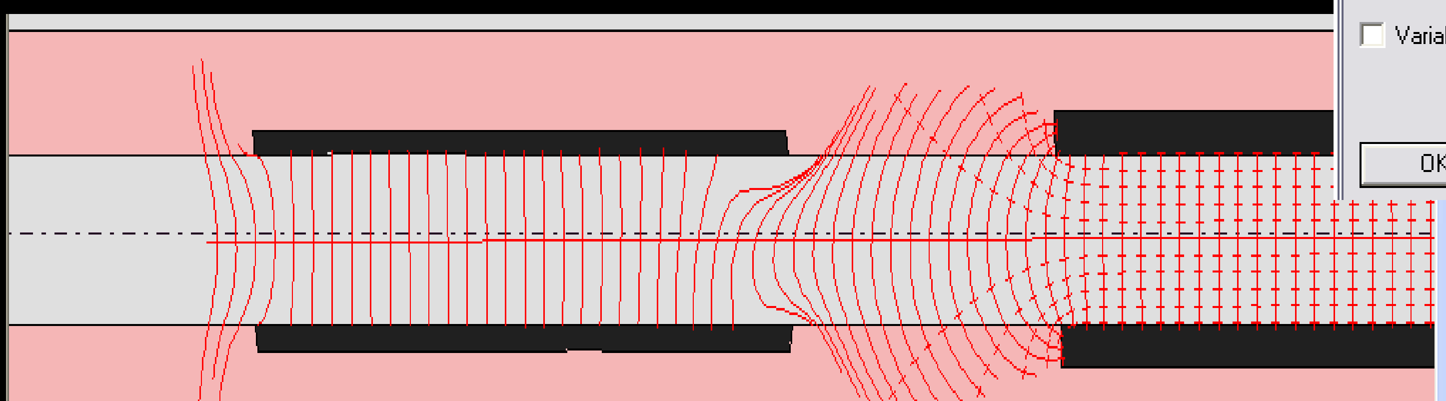
ε=3.1
PCB
LCP





Higher dielectric constant concentrates the electric field lines.

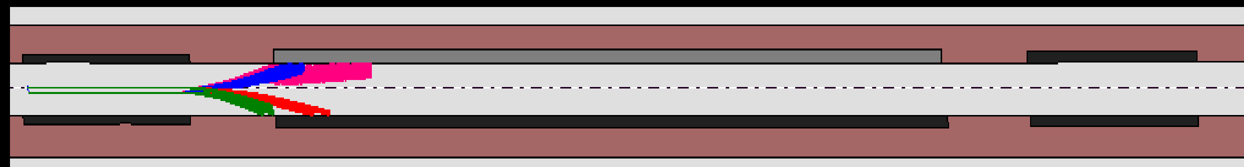
ε=1
Air



The computational tool simultaneously provides the fluid and electric field calculation and determine ion mobility movement at ambient conditions for any time of RF waveform portion .

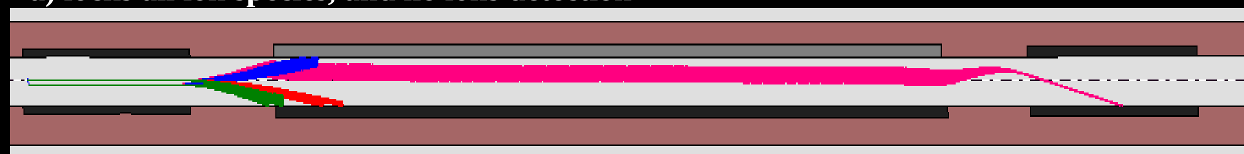
Filtration of Ions by Compensation Voltage

Vc=-27.8V



a) locks all ion species, and no ions detection

Vc= -25.8V

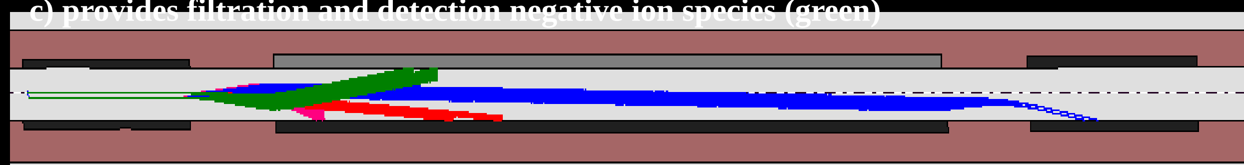


b) filtration and detection positive ions with highest alpha parameter (crimson)

Vc= -21.0V

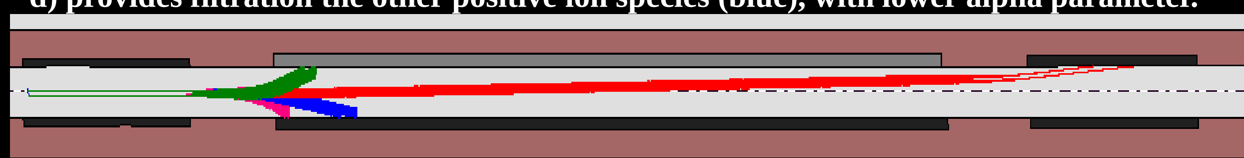
c) provides filtration and detection negative ion species (green)

Vc = -16.6V



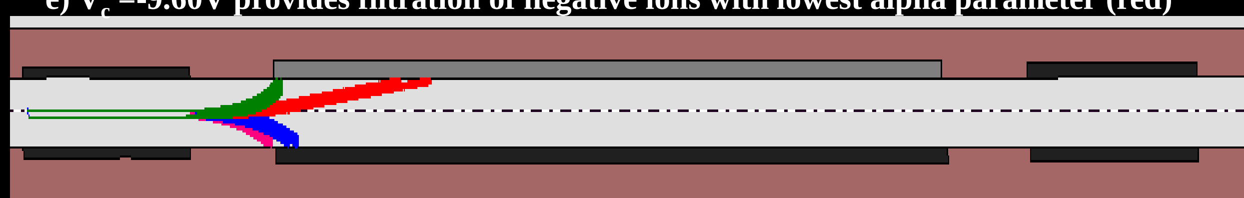
d) provides filtration the other positive ion species (blue), with lower alpha parameter.

Vc =-9.60V

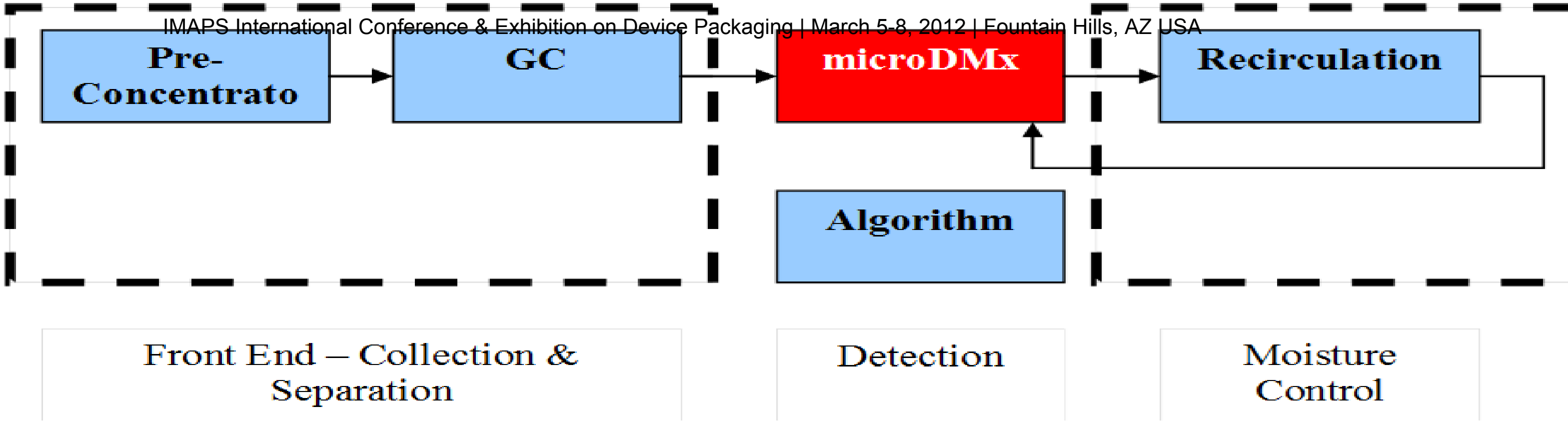


e) V_c =-9.60V provides filtration of negative ions with lowest alpha parameter (red)

Vc =-0.2 V



c) V_c =-0.2 V locks all ion species.



DMS Analyzer

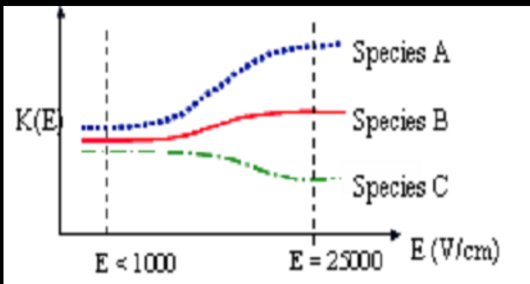
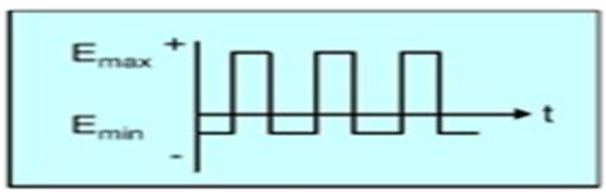
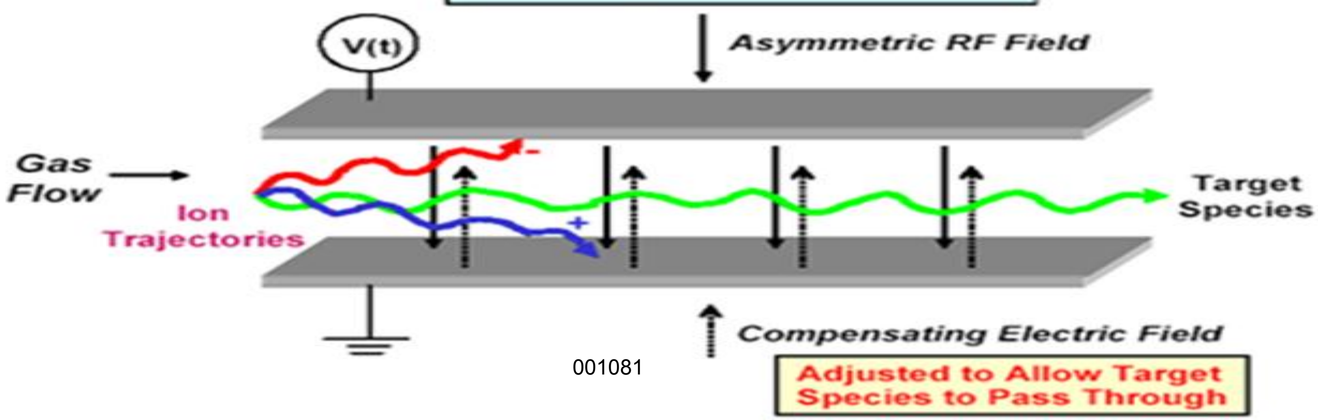
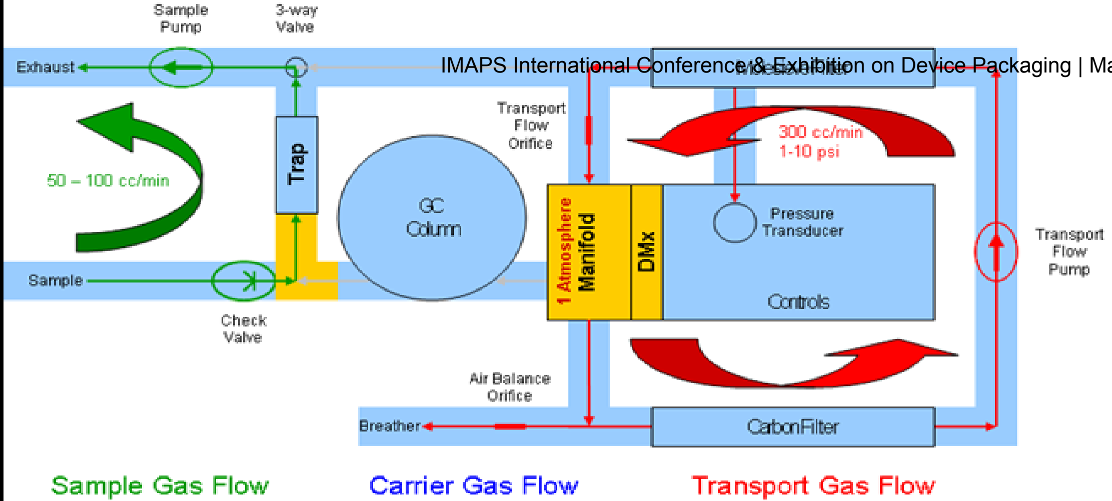


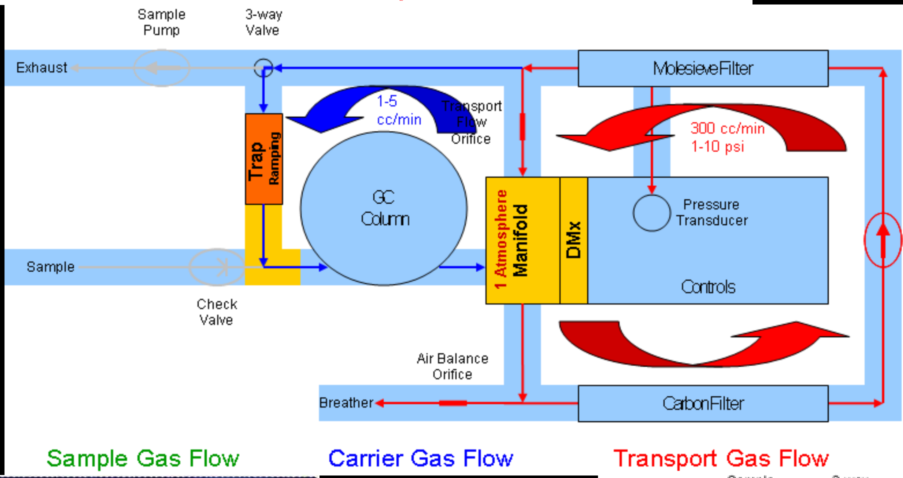
Figure 3. Ion mobility, K(E), as a function of electric field for different Species.

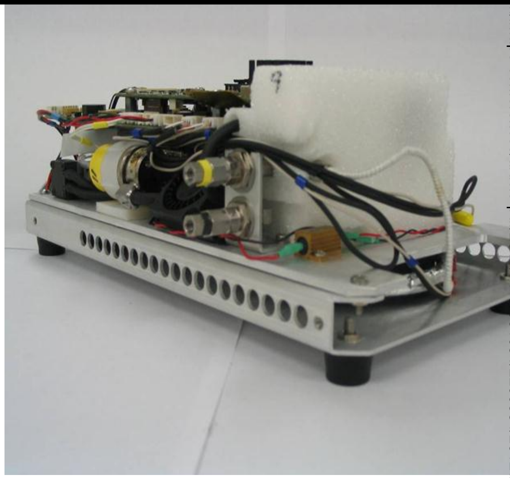


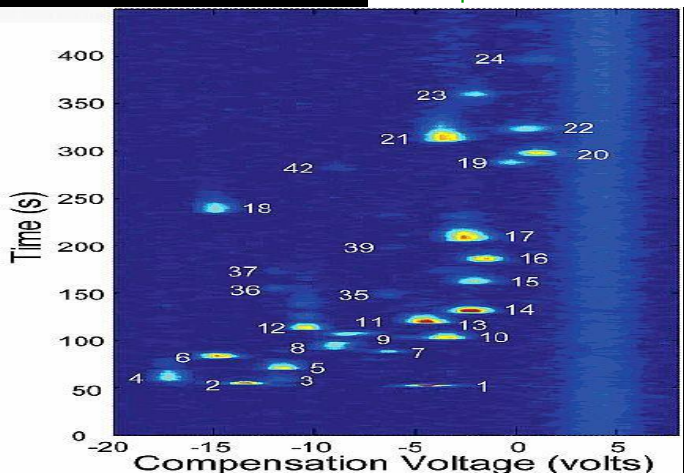


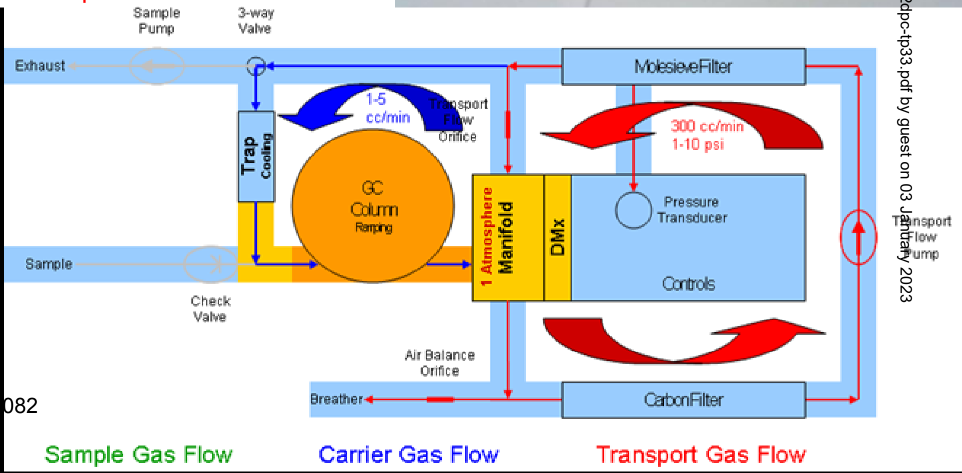
DMS System


Sample Pump
3-way Valve
Exhaust
Molesieve Filter
Transport Flow Orifice
300 cc/min
1-10 psi
50 – 100 cc/min
Trap
GC Column
1 Atmosphere Manifold
DMx
Pressure Transducer
Controls
Transport Flow Pump
Sample
Check Valve
Air Balance Orifice
Breather
Carbon Filter
Sample Gas Flow
Carrier Gas Flow
Transport Gas Flow


Sample Pump
3-way Valve
Exhaust
Molesieve Filter
1-5 cc/min
Transport Flow Orifice
300 cc/min
1-10 psi
Trap Ramping
GC Column
1 Atmosphere Manifold
DMx
Pressure Transducer
Controls
Transport Flow Pump
Sample
Check Valve
Air Balance Orifice
Breather
Carbon Filter
Sample Gas Flow
Carrier Gas Flow
Transport Gas Flow

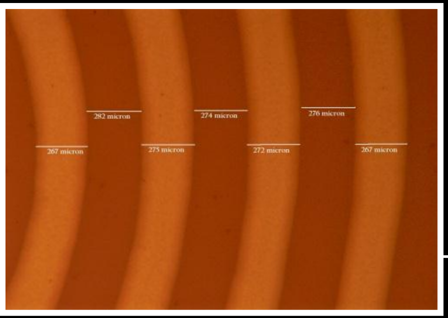


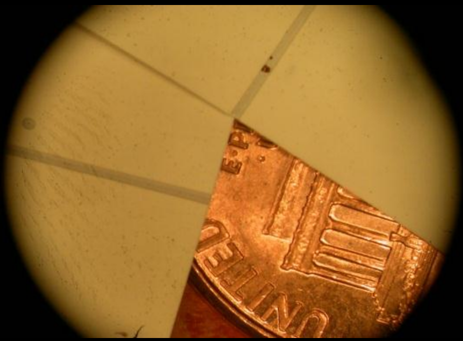

Time (s)
Compensation Voltage (volts)

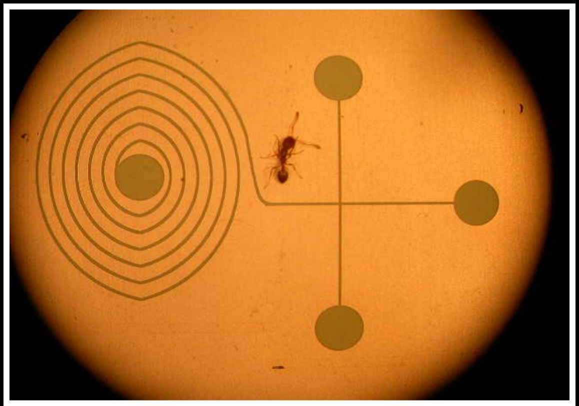

Sample Pump
3-way Valve
Exhaust
Molesieve Filter
1-5 cc/min
Transport Flow Orifice
300 cc/min
1-10 psi
Trap Cooling
GC Column Ramping
1 Atmosphere Manifold
DMx
Pressure Transducer
Controls
Transport Flow Pump
Sample
Check Valve
Air Balance Orifice
Breather
Carbon Filter
Sample Gas Flow
Carrier Gas Flow
Transport Gas Flow

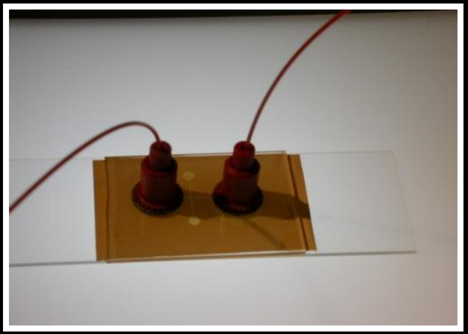
GC-DMS CHROMATOGRAPHY PCB

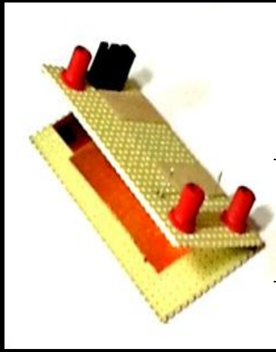
- Column etched in LCP
- LCP channel Laminated to cap layer
- Column filled with Sol-Gel for Non Volatiles Separation
- Fluorescence Detection option

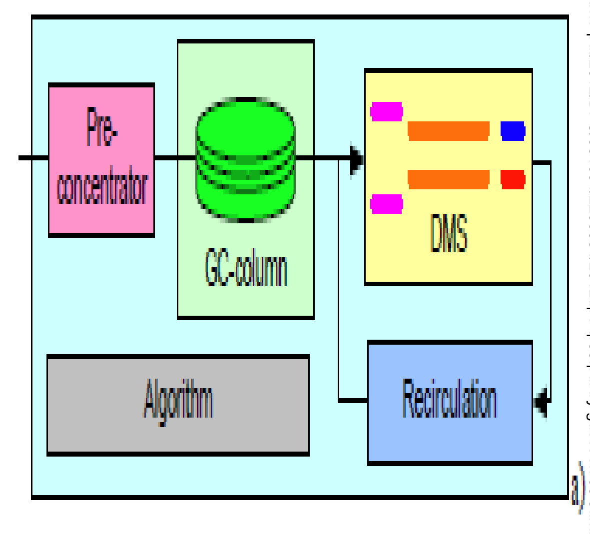












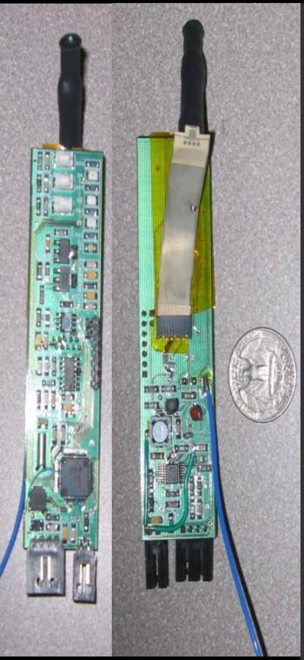
Micro-GC for Molecular Analysis

Mesoscale and MacroScale Application

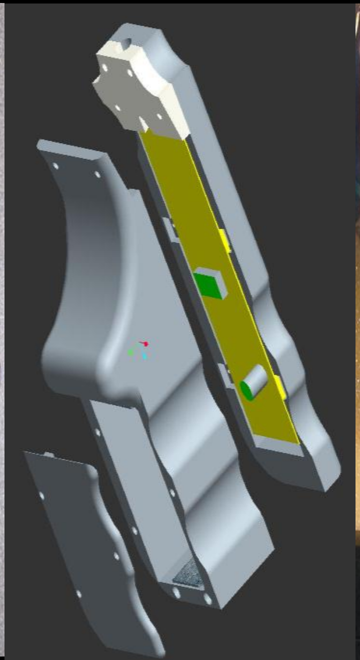
HH Genesensor System 2nd Generation

- Instrument produces comparable results to Lab equipment
- Provides on the spot “red light”/“green light” detection
- Data is stored and downloaded via USB
- Prototype runs on 3V disposable battery or via USB power

Prototype board



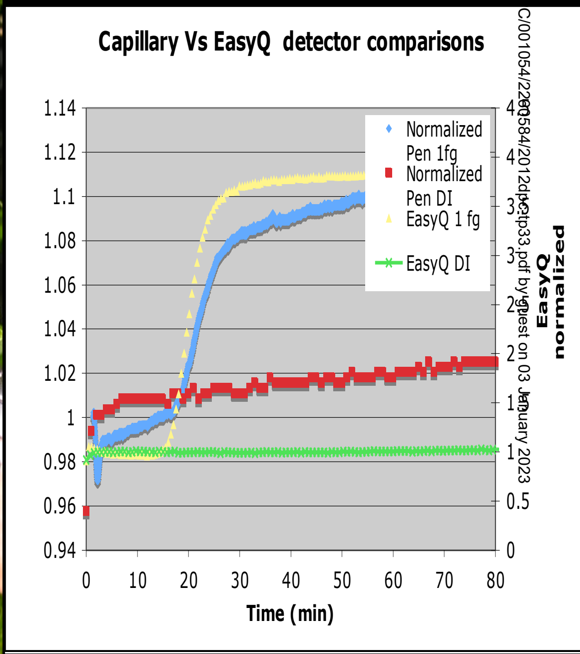
CAD packaging



Rapid prototyping

Construction of prototype

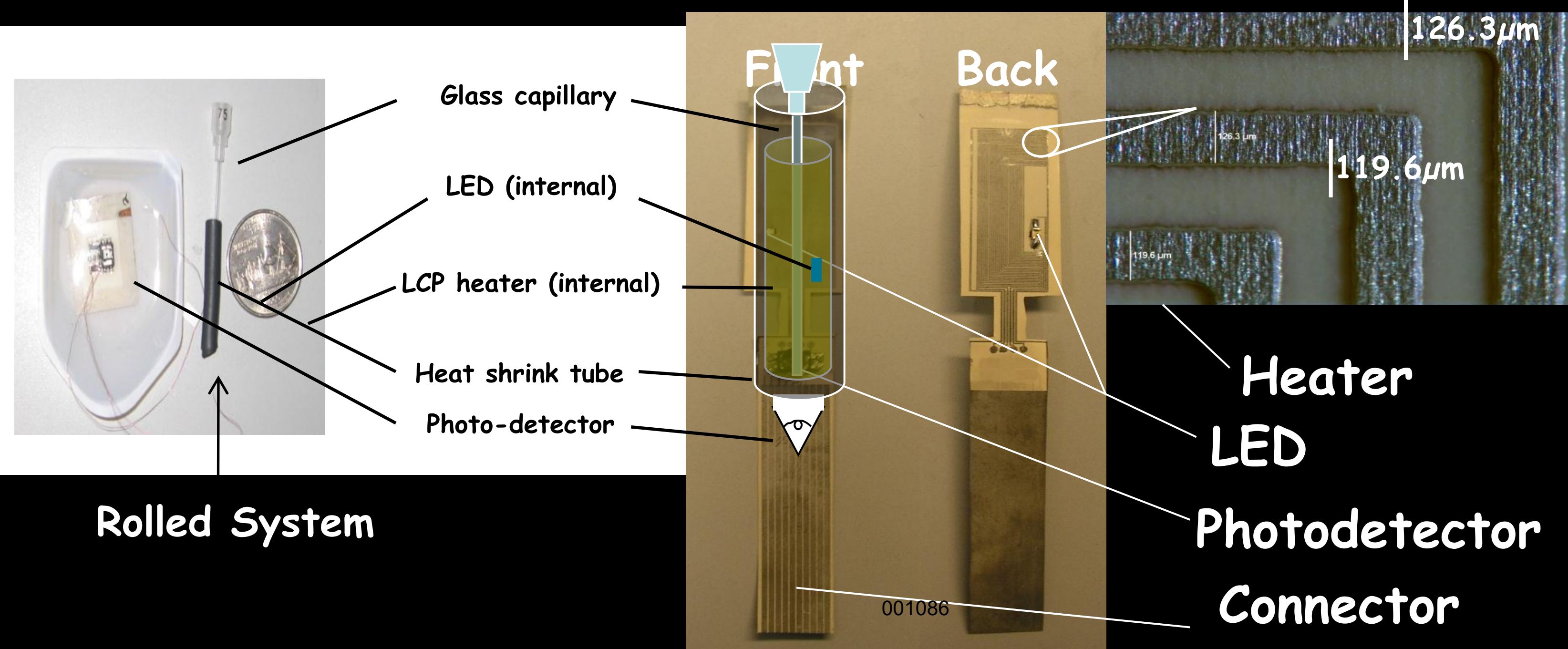
Comparative results



Handheld Microbial Genosensor Example (3rd Gen)-Phone Based

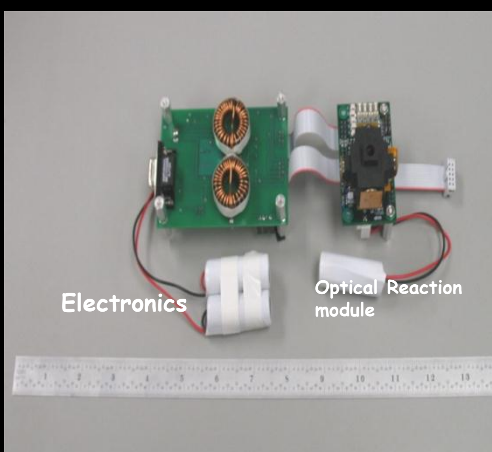
Gene amplification hand held diagnostic system based on waveguide capillary

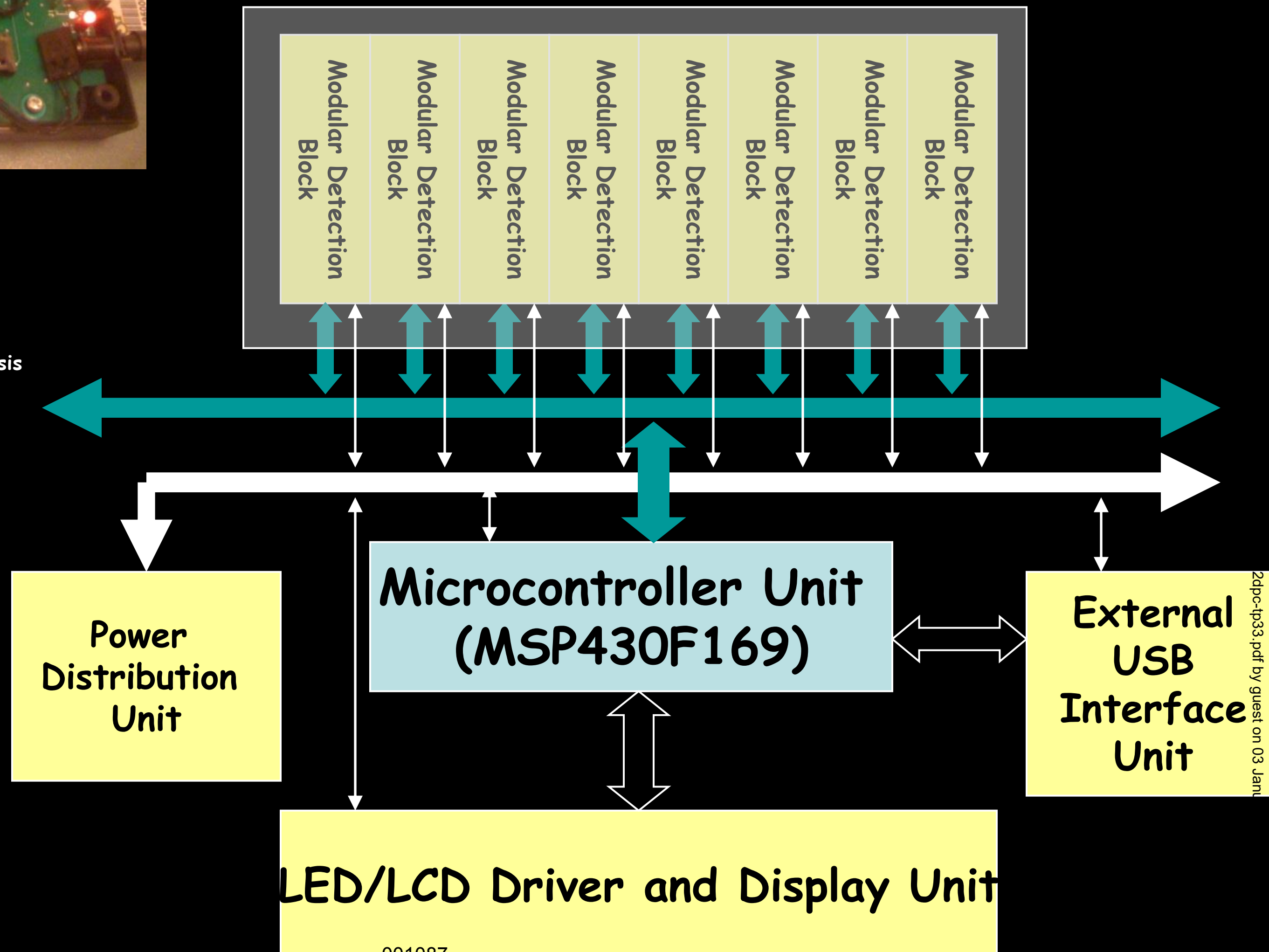
Circuits for LED, photodetector, and resistive heater produced on LCP, Micromachined PCB- Folded Embedded microfluorimeter



Multi-Channel Handheld Microbial Detector

3rd Generation Analyzer Internal View
Modules allow simultaneous multi-sample analysis





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Bio-tag Attachment Methods per Animal Class

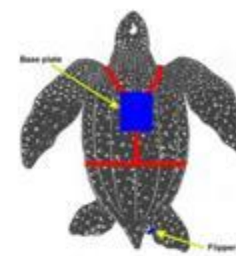
Mammalia

Pennipeds: Glued (quick setting epoxy) to head or back

Cetaceans: Attached to or near dorsal fin using suction cups

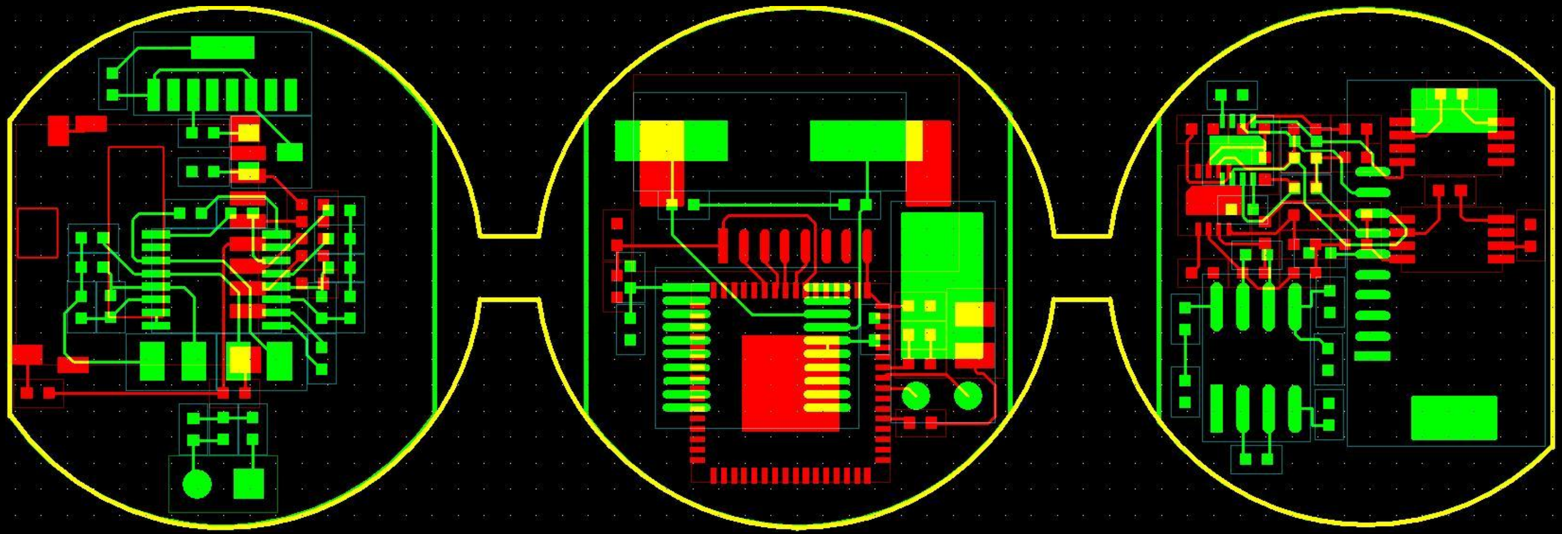
Aves: (penguins/ puffins): Attached with harness, glued or flipper tag

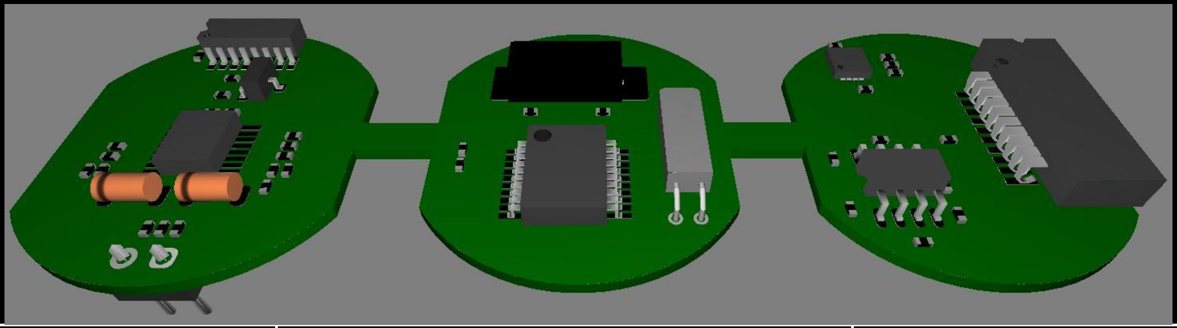
Sauropsida: Attached with harness/ glued or flipper tag



Osteichthes/ Chondrichthyes : Attached close to dorsal fin with attachment wire or internal

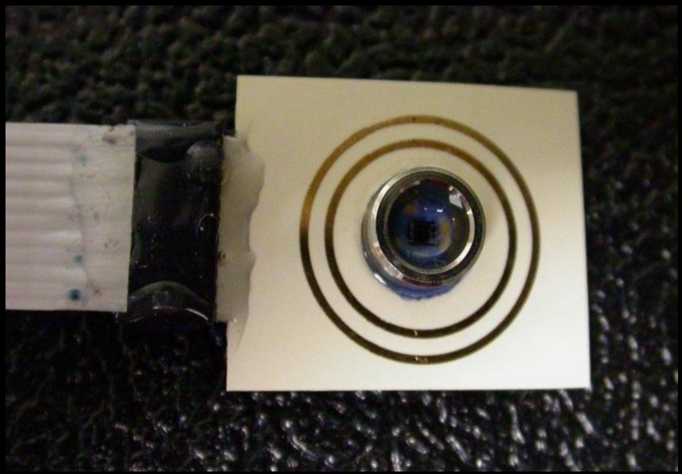
System Specifics

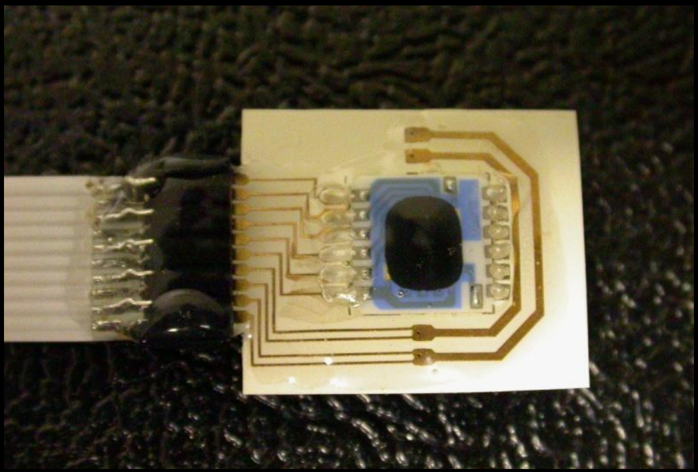




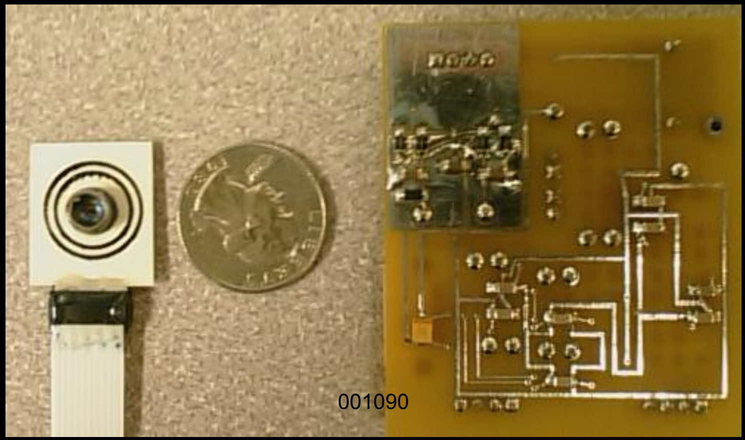
Accessory Board	Digital Control Board	Analog and Sensor Interface Board
•IrDA transceiver •microSD card •Battery connector •DCDC converter	•Low power microcontroller •IrDA controller •Programming header	•Signal conditioning •RMS-DC converters •Sensor drivers •Sensor flex connector

Mini C,T,D(pressure)





The reduced package size biotag CTD sensor system showing the temperature and pressure chip protruding through a chemically milled via hole along with concentric conductivity rings (front side image-left) and the backside image (right) with chip on flex LCP.



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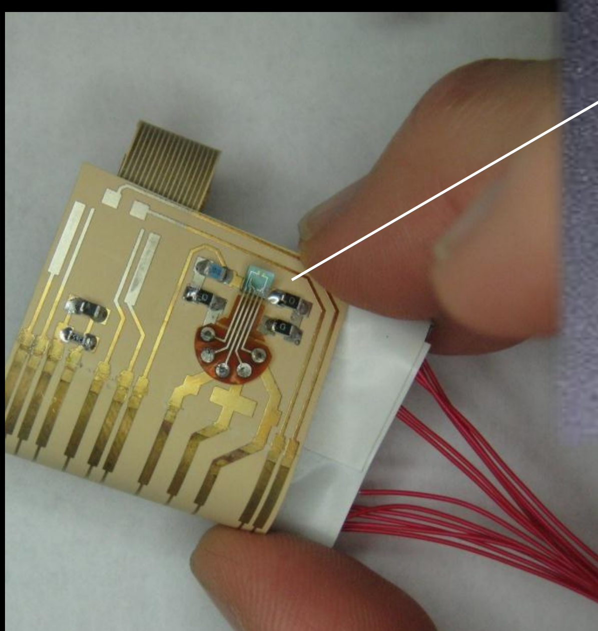
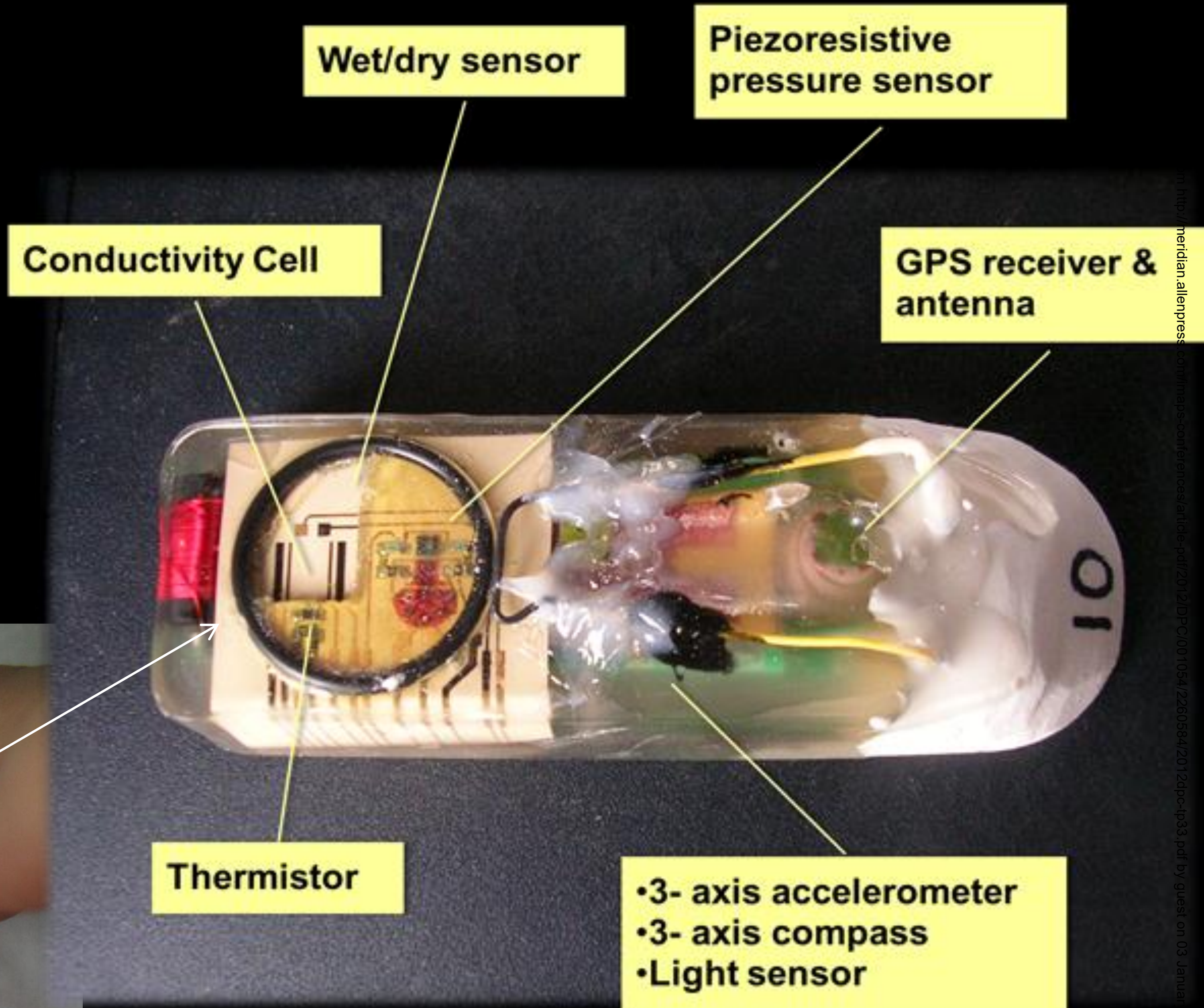
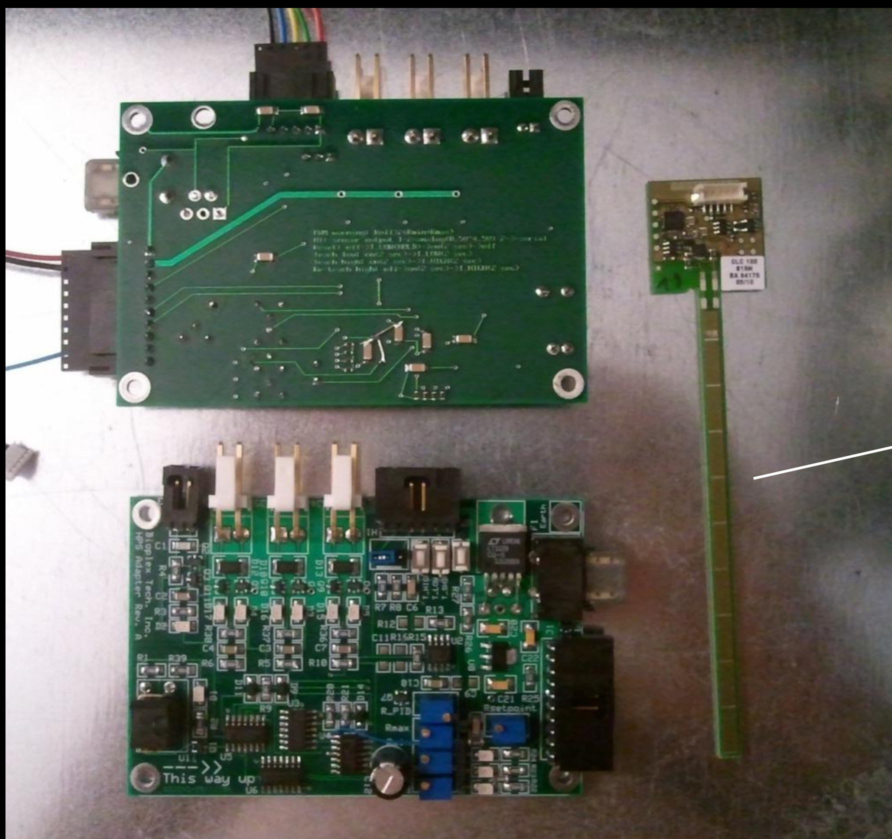


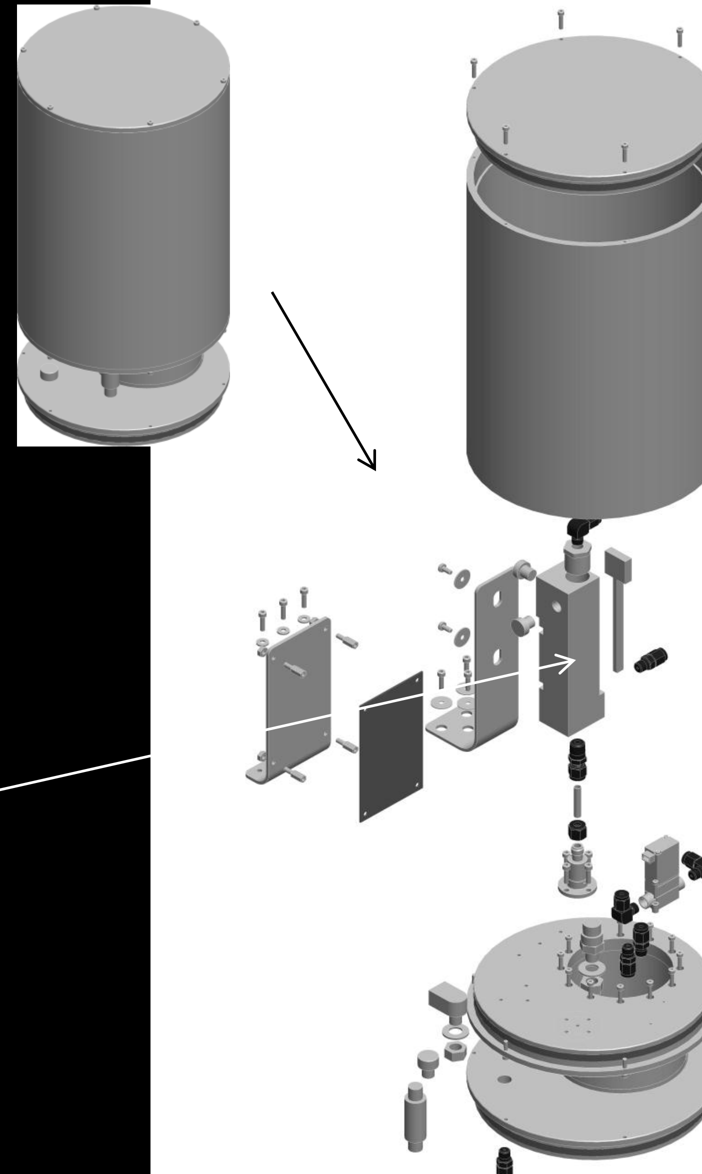


courtesy of H. Broadbent University of South Florida.

Broadbent, H.A., Ketterl, T., Reid, C., 2010. A miniature rigid/flex salinity measurement device fabricated using printed circuit processing techniques. *J. Micromech. Microeng.* 20 (8).

Mesoscale/MacroScale Application- Linear Capacitance Liquid Level Array Sensor

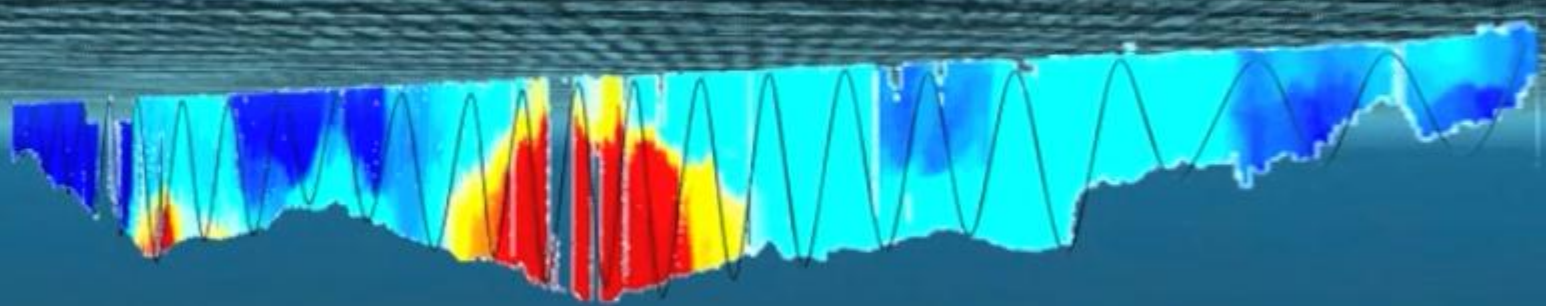




Mobile System - Macro Scale

Macro scale sensor approach for "imaging" of environmental parameters (e.g. C,T,P) within a fluid across a large field of view.

RU27_yo_30sec_data (1)



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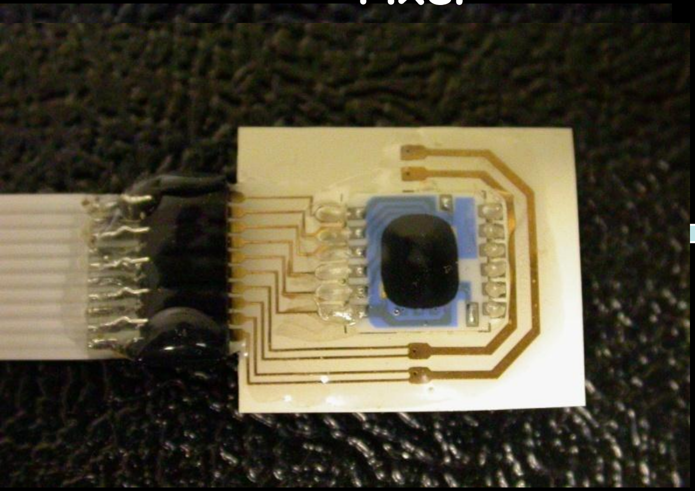
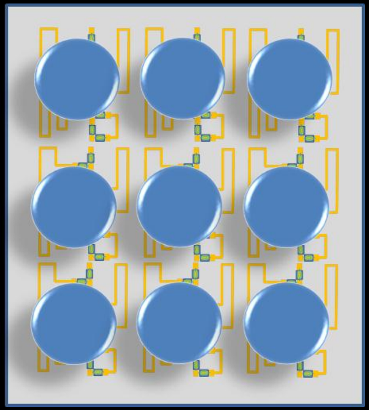
Environmental "Imaging" Application

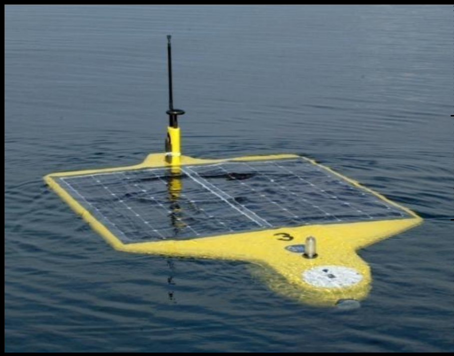
"Pixel"



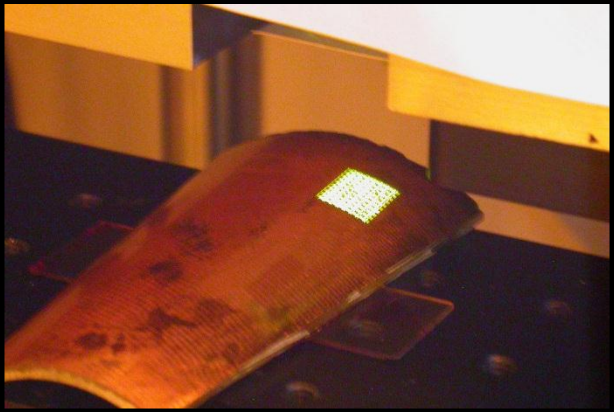
"Pixel Array "



Sensor Skins



//meridian.allenpress.com/maps-conferences/art



PCB/ PCBMEMS FOR MOBILITY

Portable

Hand held

In situ

Funding and Support:
Office of Naval Research
NSF
NAVSEA-Crane
Florida-CMSTAG
Motorola