Micro Ion-Optical Systems Technology [MIST] for Atmospheric Pressure Sources

David Fries[1], Ross Willoughby[2], Edward Sheehan[2], George Steimle[1], Stan Ivanov[1]
[1]*Center for Ocean Technology, College of Marine Science, University of South Florida, St. Petersburg, FL*
[2]*Chem-Space Associates Inc, Pittsburgh, PA*

Why are we interested in this ?

The generation of ions and charged particles at atmospheric pressure is accomplished by a variety of macroscopic design and fabrication means. Recent developments in source and optics design at atmospheric pressure show that maximum control of ion motion may be accomplished by very precise control of geometric shapes and orientations of electrode elements and fluidic pathways. These source features require spatial tolerances down to the 5-10 um range to locally control field, flow, heat transfer, and ultimately ion collection efficiency. Microsystems technologies are ideal for integration of these devices.

Within the traditional mass spec instrumentation field there is ongoing interest in new atmospheric ion source designs for more effective and versatile ion generation. Similarly, we are interested in developing new atmospheric-source based fieldable mass specs beyond the membrane based underwater mass specs we had developed in the past. (1,2) while designing for maximum ion throughput sensitivity.

We have been exploring ion optical elements for atmospheric ion sources (Willoughby et. al 2004; Sheehan et al. 2004) 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 the very small differential pumping apertures at the interface of the vacuum system reducing the gas load and decreasing the need for power hungry high throughput vacuum pumping solutions,.

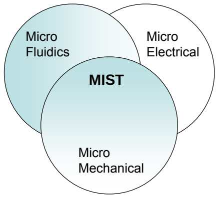
Initial work has demonstrated an increase in ion transport into the vacuum region by a factor of three to ten. Since greater ion collection efficiency can permit the reduction of the size of the aperture leading into the vacuum chamber, exponential reduction in vacuum throughput will occur. Our interest then is, how to create controlled, efficient ion transport from atmospheric pressure to vacuum pressure to enable continuous sampling portable mass spectrometer systems?

What is the solution? MIST.

The objective of the present studies is to apply alternative (non-silicon-based) microfabrication technologies to generation of atmospheric pressure ion optical devices. We have devised 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 are achieved using PCB-MEMS, also known as Polymer MEMS. PCB-MEMS is the next stage of evolution beyond simply providing electrical interconnection and mechanical support. It is the combined insertion of mechanical, fluidic, optical and electronic components into the low cost PCB landscape with high feature resolution and potentially over a large area.

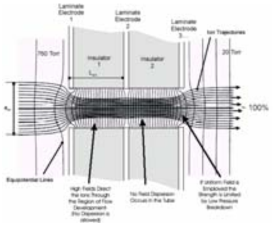
What is MIST?

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) or eventually system on a chip (SOC). Active systems may dynamically control fields and flow and contain moving mechanical components. Passive systems have no moving parts. We chose passive systems as our initial direction since they are easier to produce cost effectively.



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

Channel Classification	*Dimensional Range*
Conventional Channels	$D_h > 3mm$
MiniChannels	**$3mm > D_h > 200$ um**
MicroChannels	**200 um $> D_h > 10$ um**
Transitional Microchannels	10 um $> D_h > 1$um
Transitional Nanochannels	1um $> D_h > 0.1$um
Molecular Microchannels	0.1um $> D_h$



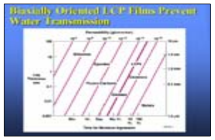
Schematic diagram of a laminated tube that ensures that the ions are presented with a uniform field as they traverse the entire length of the conductance pathway. The lack of dispersive fields at the entrance and within the tube maintains the axial trajectories of ions across the entire flow development region. Simulations generated from SIMION.

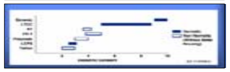
dfries@marine.usf.edu

What material to use?

In making Micro Ion-Optical Systems Technology [MIST] one could try to employ standard silicon MEMS technology but silicon has limits in area patterning, the ease of creating 3D systems and is not a favorable material for high voltage applications.
We chose to use polymer dielectrics and metal thin films, a proven combination for high field strength applications in our PCBMEMS process flow. Our particular choice for dielectric is Liquid Crystal Polymer.

The laminates we have designed and fabricated are based on liquid crystal polymers (LCP) with photodefinable bonding materials and various electroformed metals. The choice of PCBMEMS was driven by the requirement of a low investment process, a material capable of high levels of electronic systems integration, while providing a vacuum compatibility competitive to glass.





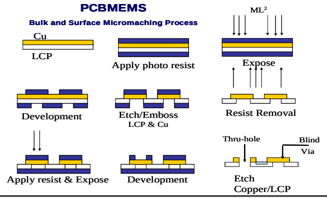
LCP Physical Properties

- ►Self- reinforcing uniform dielectric
- ►Can be fabricated in thickness multiple of 1- -5 mils
- ►No effects or defects from resin/glass intersections
- ►Biaxially-oriented gives balanced mechanical properties
- ►Good adhesion to metals
- ►Controlled low coefficient of thermal expansion
- ►Excellent barrier properties (similar to glass)
- ►High LCP melt temperatures processing
- ►Low dielectric constant (~2.9 at 20 GHz) Low dielectric)
- ►Low loss tangent (~0.002 at 20 GHz) suitable for high
- ►Micromaching Possible down to 5-10 um

Micromachining methods investigated!

Using Ion Selective Aperture Arrays as our targeted design. We tried creating our multilayer microholes arrays using (1)conventional mechanical drilling, (2)Laser drilling, (3)Photoimaging Dielectrics,(4)Etch and Deposition,(5)Combinations of Photoimaging, Etch, Deposition (i.e PCBMEMS)

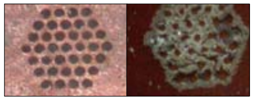
We have found the PCBMEMS process to be the most versatile in making heterogeneous organic microsystems. An enabling aspect of the LCP PCBMEMS is that the LCP etching provides a sacrificial layer for isolating the conductor *and* the conductor provides a sacrificial layer for isolating or suspending the dielectric. This process is similar in versatility as the silicon/silicon dioxide etch in standard MEMS.



Fabrications!

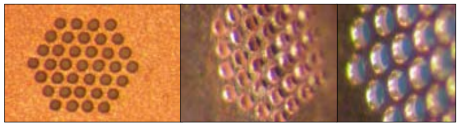
Liquid Crystalline Polymer (LCP) based designs and components have been created for atmospheric ion transport and control of conductance across an interface. Different geometries, planar and laminate, and tubular(not shown) , have been fabricated. Initial processing results indicate that this route to miniaturization and rapid fabrication is an attractive path to designing affordable, accessible integrated ion optical systems and provides optics designers advantages over standard MEMS processing.

What didn’t work well: Lasers



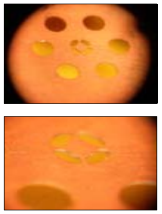
Left Image :laser micromachining processing of metal with 37element 70 um hole array
Right Image:laser micromachining of Kapton dielectric with 37 element 50 um hole array showing redeposition of material

What worked well: 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 l

Structures fabricated on top of structures using the PCBMEMS process



Process flow for PCB technology for structures

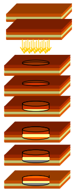
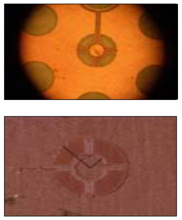
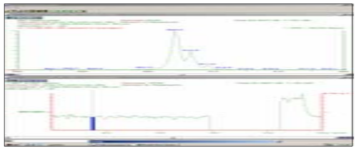


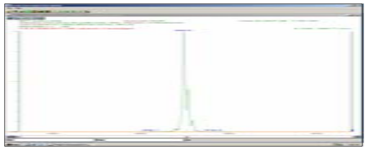
Photo-resist spinning and baking
Photo-resist exposure
Photo-resist development
Copper Etching
LCP material Etching
Metals plating
Photo-resist washing



Left Images Suspended electrode/fluid via in double-sided LCP/metal with hex element 125 um hole array. **Central** Image: PCBMEMS illustrated flow
RightImage: Additional electrode structuring on top of suspended electrode

Ions Through the Aperture Array!





Conclusion: First Steps!

Microfabrication of the polymer dielectric for fluid flow control and the metallization for electrical field control has been devised. We consider these first steps in a process that will ultimately lead us to better understanding of the combined physics (flow characteristics along streamlines, particle size, electric forces, mass and density) of atmospheric ion optics resulting in more accurate simulation results, more complex ion optical systems and real control of the ion stream.

References

Fries DP, Short R, Toler, S, Lembke, C, Kerr M and Byrne R. Mass spectrometry in the hydrosphere. 49th Proceedings of the American Society for Mass Spectrometry. Long Beach, California, 2000.
Fries DP, Short RT, Langebrake, LL, Patten JT, Kerr ML, Kibelka G, Burwell DC and Jalbert JC. In water field analytical chemistry: mass spectrometers, robots, numerical models for wide area chemical plume localization. Field Anal. Chem. Tech. Journal 5: 121-130.D. 2001.
Willoughby RC, Sheehan EW and Fries DP. Transmission of Ions Through Conductance Pathways from Atmospheric Pressure. Presented at 52nd American Society for Mass Spectrometry Conference. Nashville, TN. May 23-27 2004.
Sheehan EW, Willoughby RC and Fries DP. Atmospheric Pressure Focusing. Presented at 52nd American Society for Mass Spectrometry conference. Nashville, TN. May 23-27 2004.