A 2kPa Per Stage and 1.3sccm Flow Rate Modular Two-Stage Electrostatic Gas Micropump with Stiffened Drive Electrodes

Amin Sandoughsaz[1], Luis P. Bernal[2], Khalil Najafi[1]
[1]Electrical Engineering and Computer Science, University of Michigan, Ann Arbor, Michigan, USA
[2]Aerospace Engineering, University of Michigan, Ann Arbor, Michigan, USA

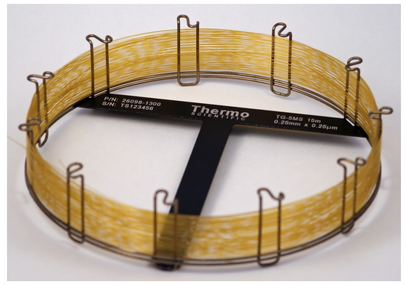
Motivation/Application

Gas Pumps needed in:
- Gas Chromatography Systems
- Mass Spectrometers
- Environmental and Health Monitoring Systems
- Lab-On-Chip Devices

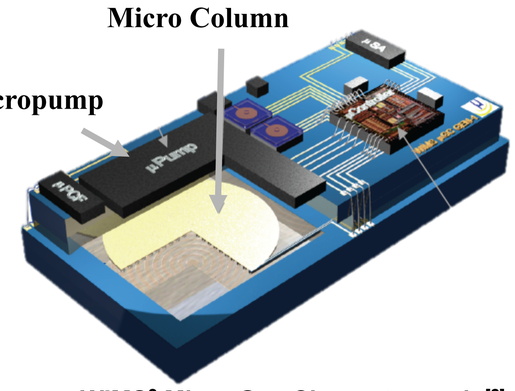
Portable Systems require Pumps with:
- Low Power Consumption
- Low Weight
- Small Size
- Low Cost
- High Pressure/High Flow Rate

Gas Chromatography systems:
Require Flow Rate to move the mass through the long column

Mass Spectrometry Systems:
Require High Vacuum to increase ion mean free path (by reducing the collision)

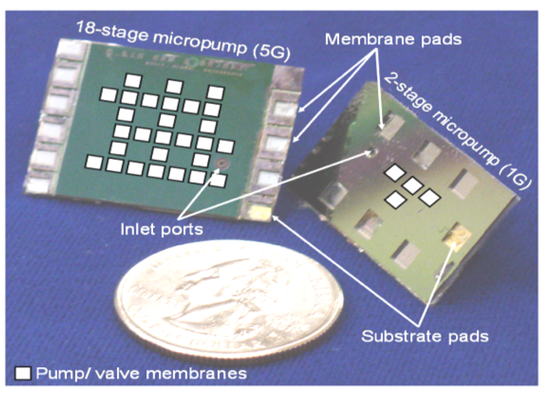


Gas Chromatograph Column [1]

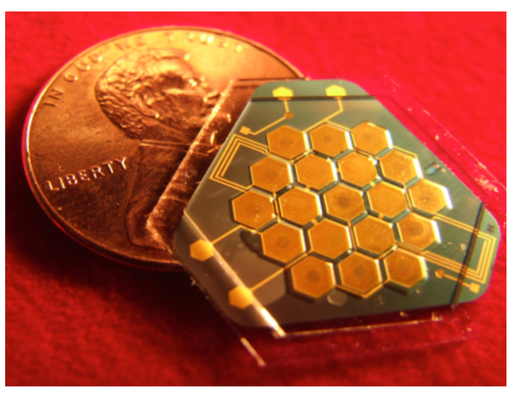


WIMS² Micro Gas Chromatograph [2]

Prior Work on Micropump by WIMS²



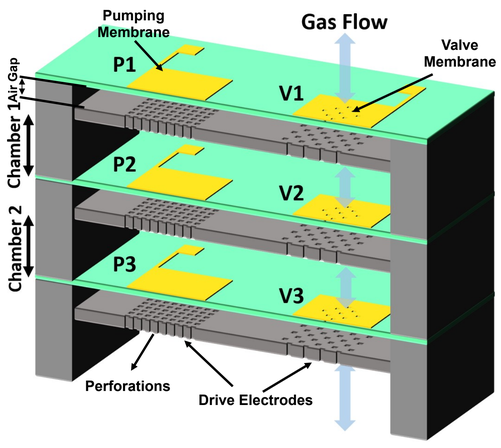
Michigan Gas Micropump [3]



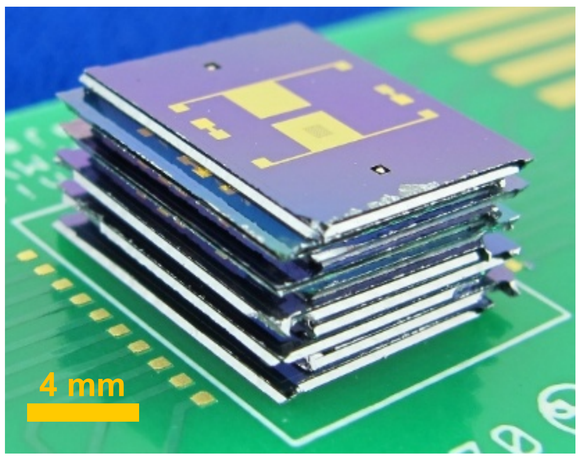
Honey Comb Micropump [4]

Coplanar Design: Number of cascaded stage preset by layout design; not modular

Modular Stacked Design



Cross-Sectional View

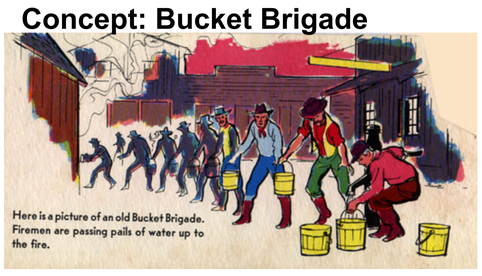


Stacked Micropump Chips

Stacked Design: single stages cascaded post-fabrication; modularity over number of stages and volume ratio

Principle of Operation

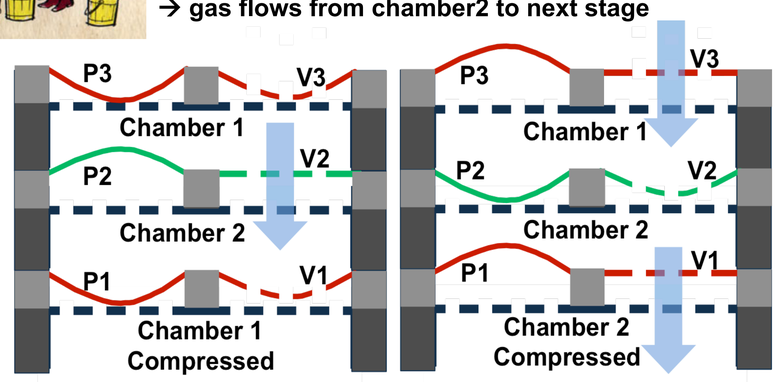
Concept: Bucket Brigade



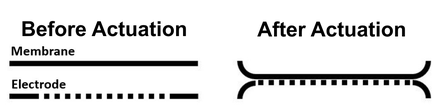
Pumping Cycle 1:
Chamber 1 compressed by P_2,P_3 membranes, V_3 closed, V_2 open → gas flows from chamber 1 to chamber 2

Pumping Cycle 2:
Chamber 1 decompressed, V3 open →sucks in gas
Chamber 2 compressed by P_1, P_2, V_2 closed, V_1 open → gas flows from chamber2 to next stage

- Membrane actuation: Electrostatic
- Every other stage have the same actuation signal
- Adjacent stages 180° out of phase
- Membranes timing is critical

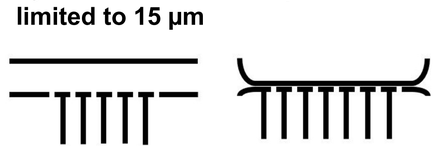


Design Modifications

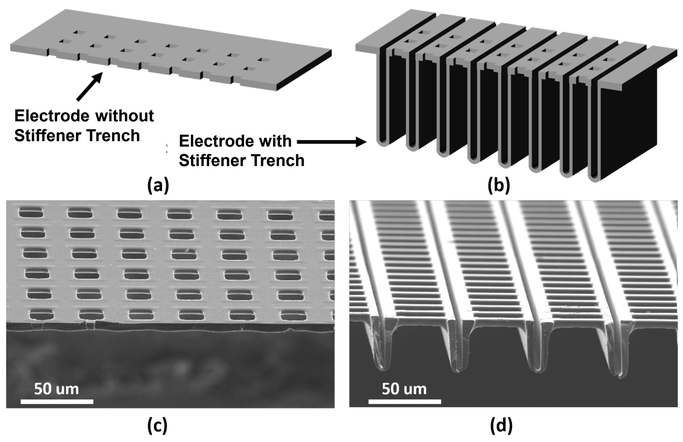


(a) First generation without stiffener

(b) simplest stiffener structure, not practical in terms of fabrication, electrode thickness is determined by Boron diffusion depth which is limited to 15 µm

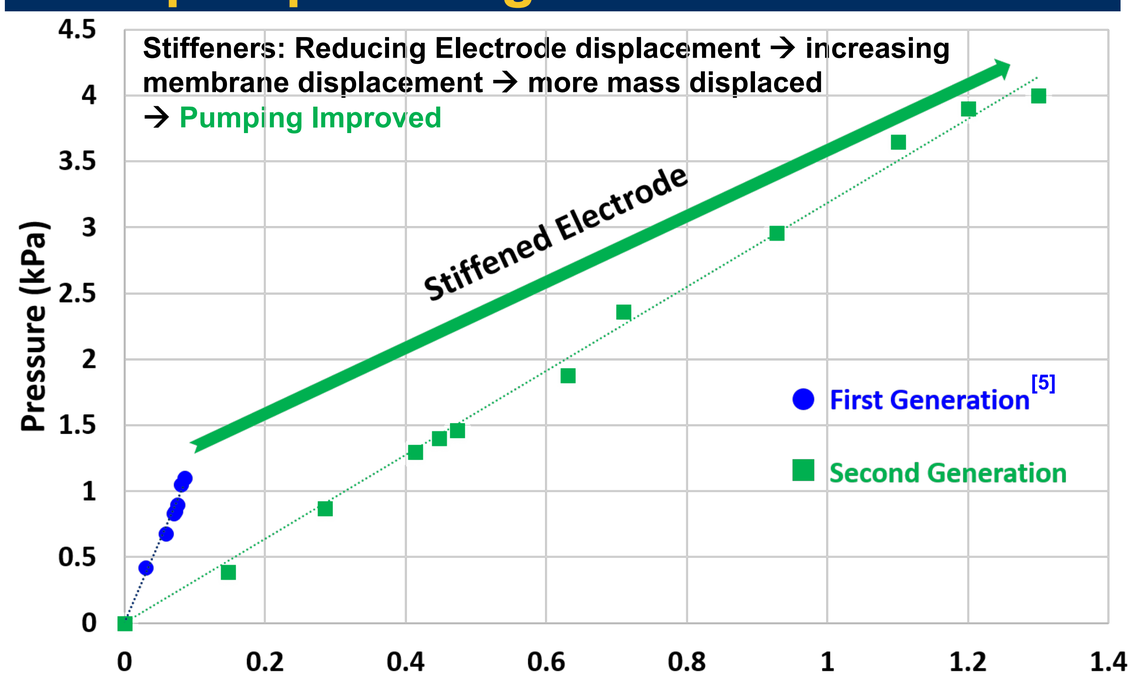


(c) Second generation stiffener structure: Deep vertical p++ doped trenches are added to the standard electrodes as the stiffener.



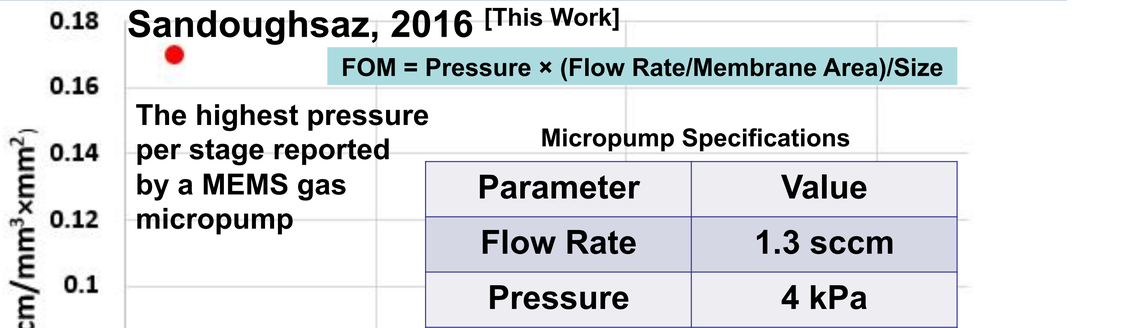
Schematic view of first generation devices electrode (a) without stiffener, (b) second generation devices electrode with 40 µm deep stiffener trenches. SEM image of (c) first generation device electrode (~8um Boron doped Silicon), (d) second generation device electrode with 40um Boron doped stiffener trench.

Micropump Testing Results



Pumping Performance of 3-chips Stacked Micropumps for Various Generations

Comparison with Prior Works



Micropump Specifications

Parameter	Value
Flow Rate	1.3 sccm
Pressure	4 kPa
Actuation frequency	24 kHz
Size	5.5x4x1.5 mm³

Micropump Performance Comparison with State Of The Art

References

[1] http://www.thermofisher.com
[2] E. Zellers, et al., in Proc. Solid State Sens. Actuators, Microsyst. Workshop, 2004
[3] H. Kim, et al., in Proc. MEMS 2007
[4] A. Besharatian, et al., in Proc. MEMS 2012
[5] A. Sandoughsaz, et al., in Proc. Transducers, 2015
[6] B. Büstgens, et al., ., in Proc. MEMS 1994
[7] K. P. Kämper, et al., in Proc. MEMS 1998
[8] C. Cabuz, et al., in Proc. MEMS 2001
[9] A. Olsson, et al., Sensors and Actuators A Physical, 1998