iGCx: Fully Electronic Microfabricated Gas Chromatographs

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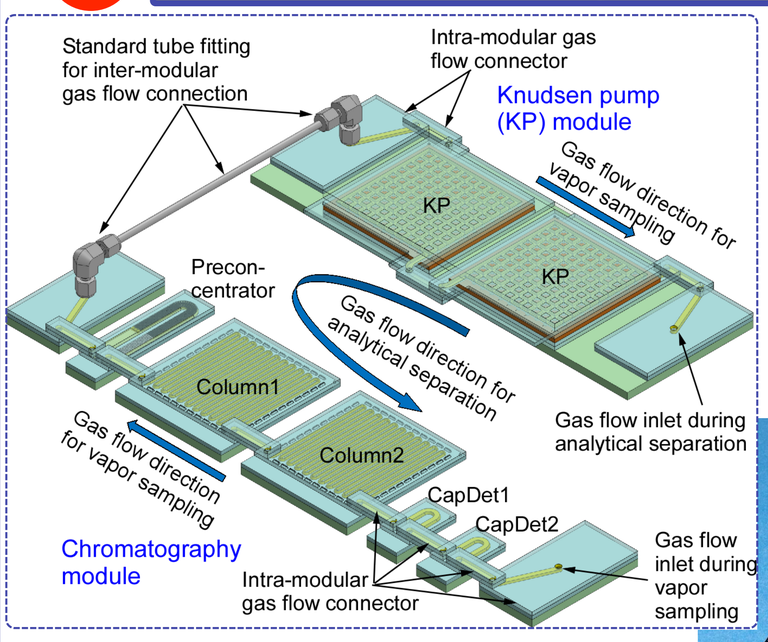
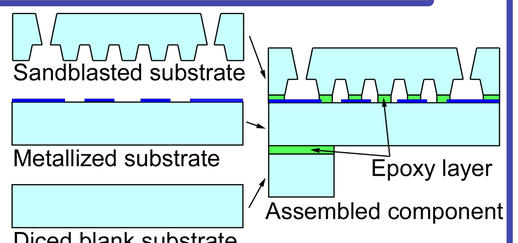
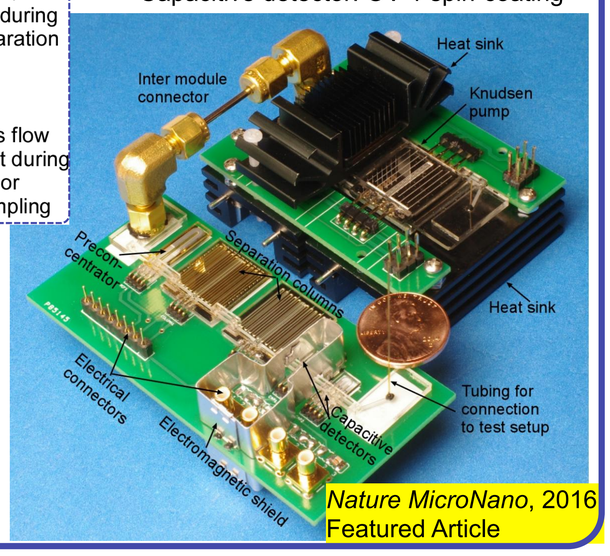
Summary: This work presents a series of integrated micro gas chromatography (μGC) systems. The latest generation, named *iGC3*, is a complete system in which all the components are lithographically microfabricated and electronically interfaced. The *iGC3* includes a bi-directional Knudsen pump, a preconcentrator, separation columns, and capacitive gas detectors, forming a complete μGC system with a foorprint of ≈8×10 cm^2. The system uses room air as carrier gas. All the fluidic components of the system are fabricated by a common three-mask lithographic process. The system is used to experimentally demonstrate analysis of 19 chemicals with concentration levels of ppm to ppb in room air. This set of chemicals represents a variety of common indoor air pollutants, among which benzene, toluene, and xylenes (BTX) are of particular concern. Repeatable analyses at 10-50% humidity levels have also been demonstrated experimentally.

1 *iGC3* Design and Fabrication





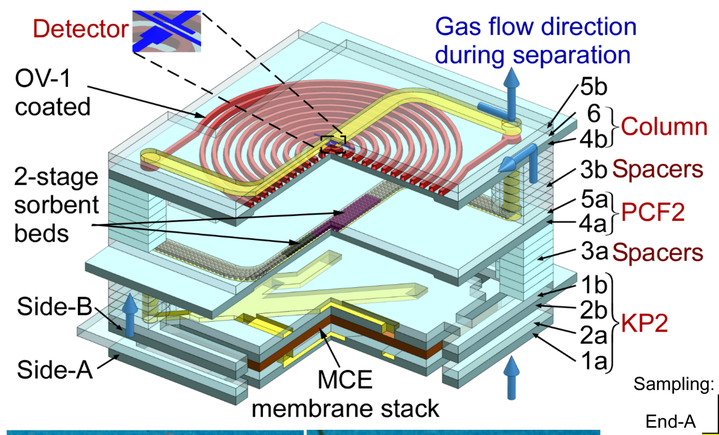
Post-processing also includes:
- Knudsen pump: epoxy sealing
- Column: stationary phase coating
- Preconcentrator: sorbent packing
- Capacitive detector: OV-1 spin-coating



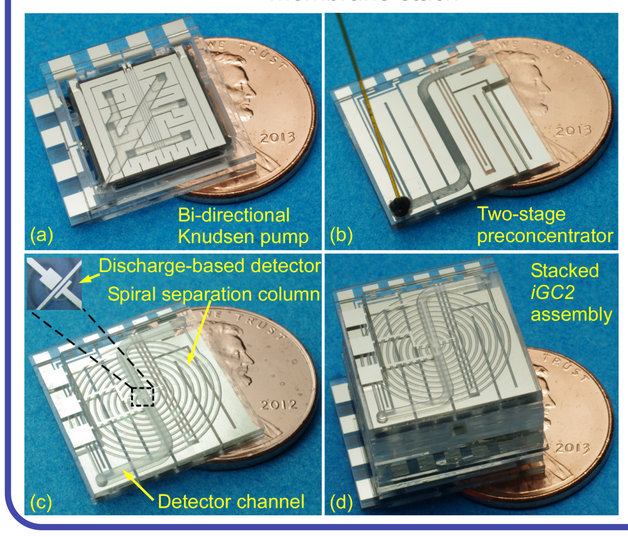
Nature MicroNano, 2016
Featured Article

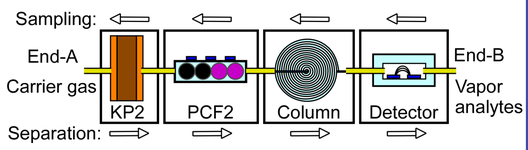
Features
- Fully electronic
- All fluidic components microfabricated by a common low-cost, three-mask process
- Compatible with room air as carrier gas
- Complementary capacitive detectors
  - Enhance vapor recognition
  - Resolve co-eluting peaks

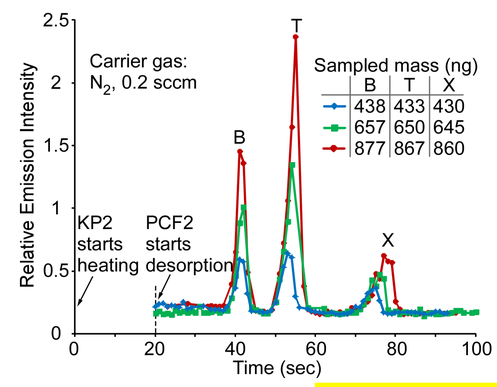
Prior Work: *iGC2*



- Bi-directional flow provided by a bi-directional pump in a valveless, 4 cm^3 stacked architecture
- The discharge-based detector relies on optical interface and requires carrier gas





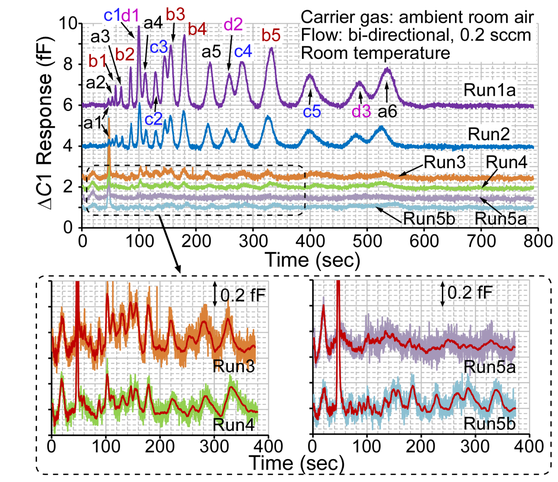


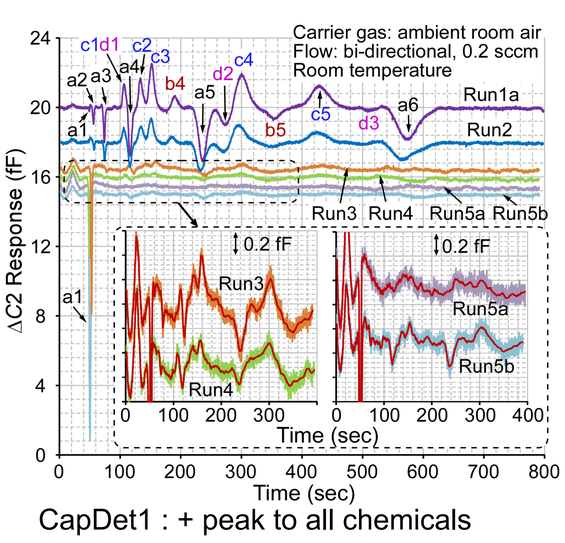
IOP JMM, 2014

2 *iGC3* Experimental Results

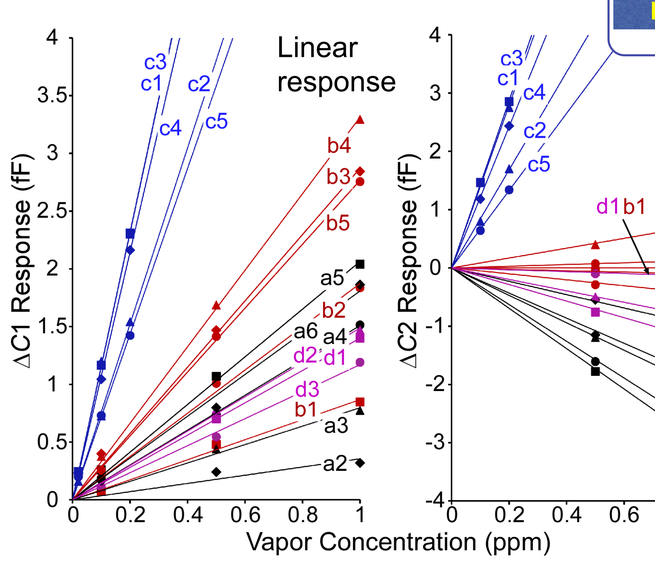
Quantitative Analysis
- 19 chemicals
- BTX and other indoor pollutants
- ppb-ppm concentrations

Run ID:			1	2	3	4	5	
			1a				5a	5b
Chemicals		Polarity	Concentration (ppm)					
a1	pentane C5	nonpolar	1	0.5	20	10	10	
a2-a6	n-alkanes C6-C9	nonpolar	1	0.5	0.1	0.05	0.01	
b1-b5	benzene, toluene, m-xylene, o-xylene, mesitylene	nonpolar	1	0.5	0.1	0.05	0.01	
c1-c5	hexanal, chlorobenzene, chlorohexane, 4-chlorotoluene, 1,3-dichlorobenzene	mildly polar	0.2	0.1	0.02	0.01	0.002	
d1-d3	cycloheptane, α-pinene, 3-carene	nonpolar	1	0.5	0.1	0.05	0.01	
Sampling time (min.)			30				120	

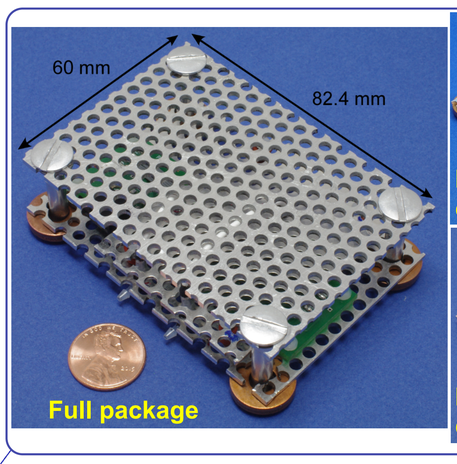




CapDet1 : + peak to all chemicals
CapDet2 : +/− peak to different chemicals



Repeatable analysis using polluted air sample with 10-50% humidity as carrier gas
Mimicking unattended field monitoring scenarios



Recent effort: Knudsen pump in a metal mesh package

Metrics (for *iGC3* separation)	*iGC3* 2-stage pump	New 1-stage pump
Blocking pressure	1 kPa	0.85 kPa
Max. flow	0.5 sccm	0.6 sccm
System flow	0.2 sccm	0.2 sccm
Power	3.2 W	2 W

New pump *vs.* prior *iGC3* pump
- Simpler manufacturing
- Greater power efficiency

IEEE MEMS, 2017

Known applications:
- Indoor pollutants

Potential applications:
- Outdoor pollutants
- Automobiles
- Ground water
- Soundless surveillance
- Medical

US EPA TO-14A Compound List
- 30 compounds within *iGC3* range
- 7 compounds tested in *iGC3*

1. Dichlorodifluoromethane
2. Methyl Chloride
3. 1,2-dichloro-1,1,2,2-tetrafluoroethane
4. Vinyl Chloride
5. Methyl Bromide
6. Ethyl Chloride
7. Trichlorofluoromethane
8. 1,1-dichloroethene
9. Dichloromethane
10. 3-chloropropene
11. 1,1,2-trichloro-1,2,2-trifluoroethane
12. 1,1-dichloroethane
13. Cis-1,2-dichloroethene
14. Trichloromethane
15. 1,2-dichloroethane
16. 1,1,1-trichloroethane
17. Benzene
18. Carbon Tetrachloride
19. 1,2-dichloropropane
20. Trichloroethene
21. Cis-1,3-dichloropropene
22. Trans-1,3-dichloropropene
23. 1,1,2-trichloroethane
24. Toluene
25. 1,2-dibromoethane
26. Tetrachloroethene
27. Chlorobenzene
28. Ethylbenzene
29. m,p-xylene
30. Styrene
31. 1,1,2,2-tetrachloroethane
32. o-xylene
33. 4-ethyltoluene
34. 1,3,5-trimethylbenzene
35. 1,2,4-trimethylbenzene
36. m-dichlorobenzene
37. Benzyl Chloride
38. p-dichlorobenzene
39. o-dichlorobenzene
40. 1,2,4-trichlorobenzene
41. Hexachlorobutadiene

Publications:
[1] Y. Qin, Y.B. Gianchandani, "*iGC2*: an architecture for micro gas chromatographs utilizing integrated bi-directional pumps and multi-stage preconcentrators," *IOP Journal of Micromechanics and Microengineering*, vol. 24, no. 6, 065011(10 pp.), 2014.
[2] Y. Qin, Y. Gianchandani, "A Fully Electronic Microfabricated Gas Chromatograph with Complementary Capacitive Detectors for Indoor Pollutants," *Nature Microsystems and Nanoengineering*, vol. 2, 15049(11 pp.), 2016, (Featured Article)
[3] Q. Cheng, Y. Qin, Y.B. Gianchandani, "A Bidirectional Knudsen pump with Superior Thermal Management for Micro-Gas Chromatography Applications," *IEEE International Conference on Micro Electro Mechanical Systems (MEMS)*, Las Vegas, Nevada, Jan. 2017

Patent: Y.B. Gianchandani, Y. Qin, "Integrated Fluidic System for Gas Chromatography," US 61/824,573, patent pending
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