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Offset passive MEMS valves with tuned spring constants for Micro-gas-analyser sample handling

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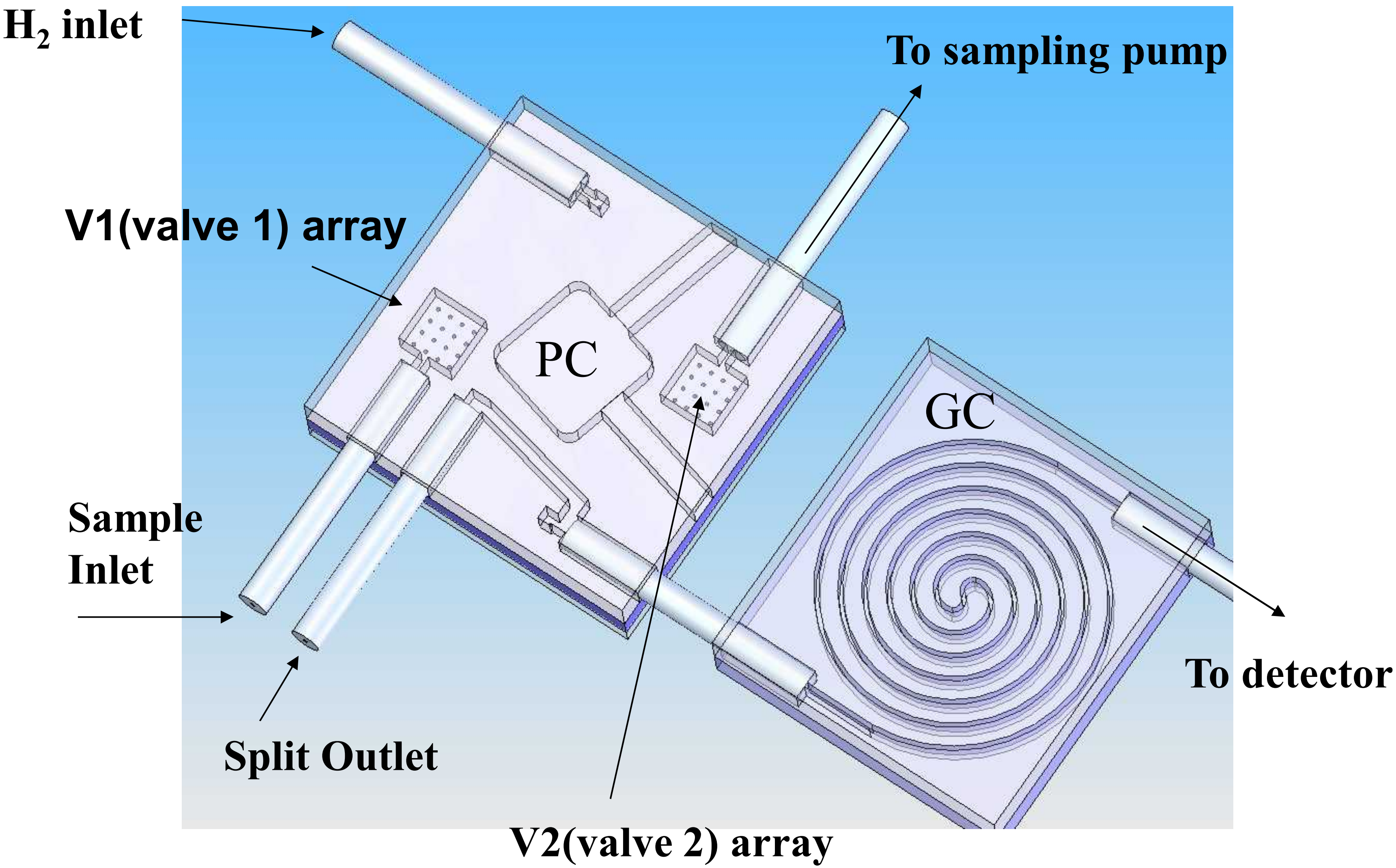
Figure 1. MGA Phase 2 Hybrid Chips

MEMS valves on PC chip limit inlet volume allowing fast separations



Valve 2 Specifications

- During collection valve 2 is open for air flow, pressure drop across valve 2 is low (2.5 to 5 psig), want large airflow at low pressure drop.
- During GC charging valve 2 is closed by high pressure H_2 (45 to 50 psig), want low leak rate of H_2 with valve closed.
- Specifications
  - Open at low pressure (2.5 to 5 psig) – 60 ml/min air
  - Closed at high pressure (45-50 psig) – 0.06 ml/min (1 μl/sec) H_2
  - Fit within power and size constraints of system – 1 cm^3 and 0.1 J/(cycle-valve)

Table 1 – Valve specifications

Valve 2 design concept – normally open valve

- This valve is open one-way at low pressures and closed in the same flow direction at higher pressures. So it is not a one-way or check valve, but rather a check valve with an offset.

- Our concept addresses this issue using a valve spring with a stiffness set so that at low pressure the valve body does not deflect very far and the normally open valve stays open. While at high pressure the spring deflects significantly and the valve closes against the valve seat stopping the flow.

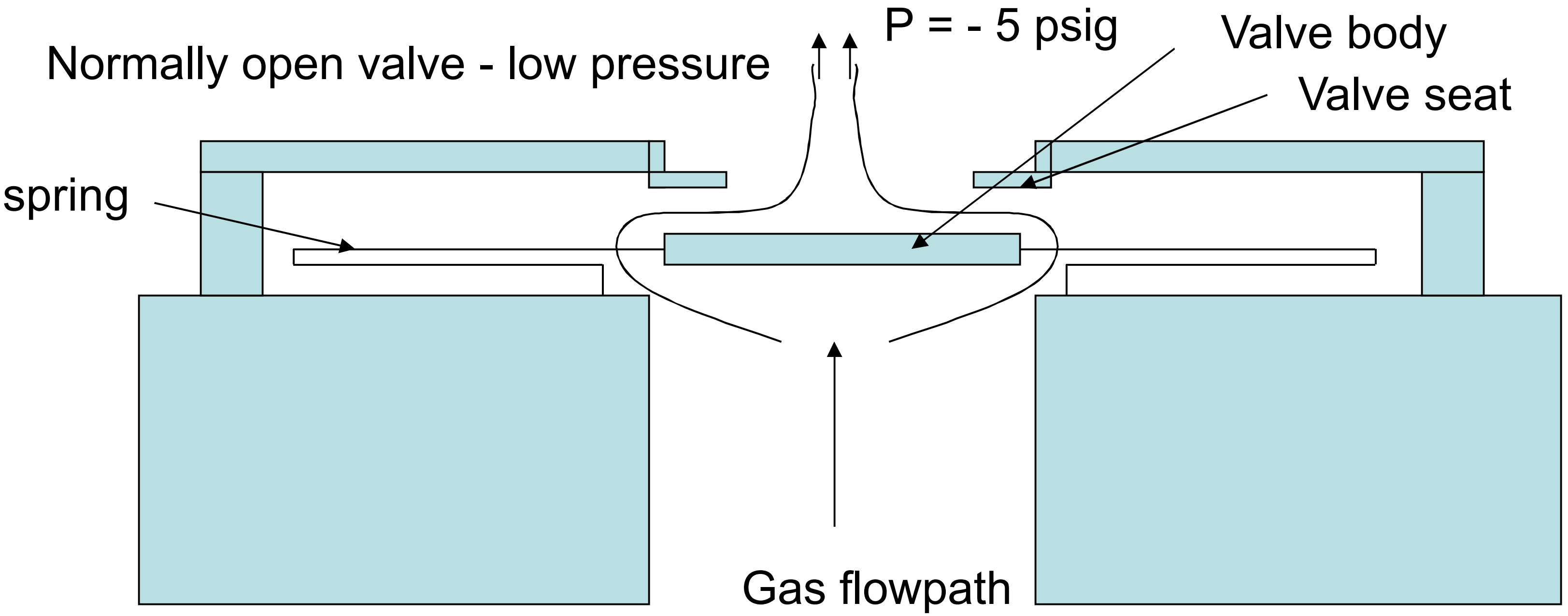


Figure 2. Valve operating concept.

Valve 2 design concept – valve closed

Valve body travel to close is ~5 microns.

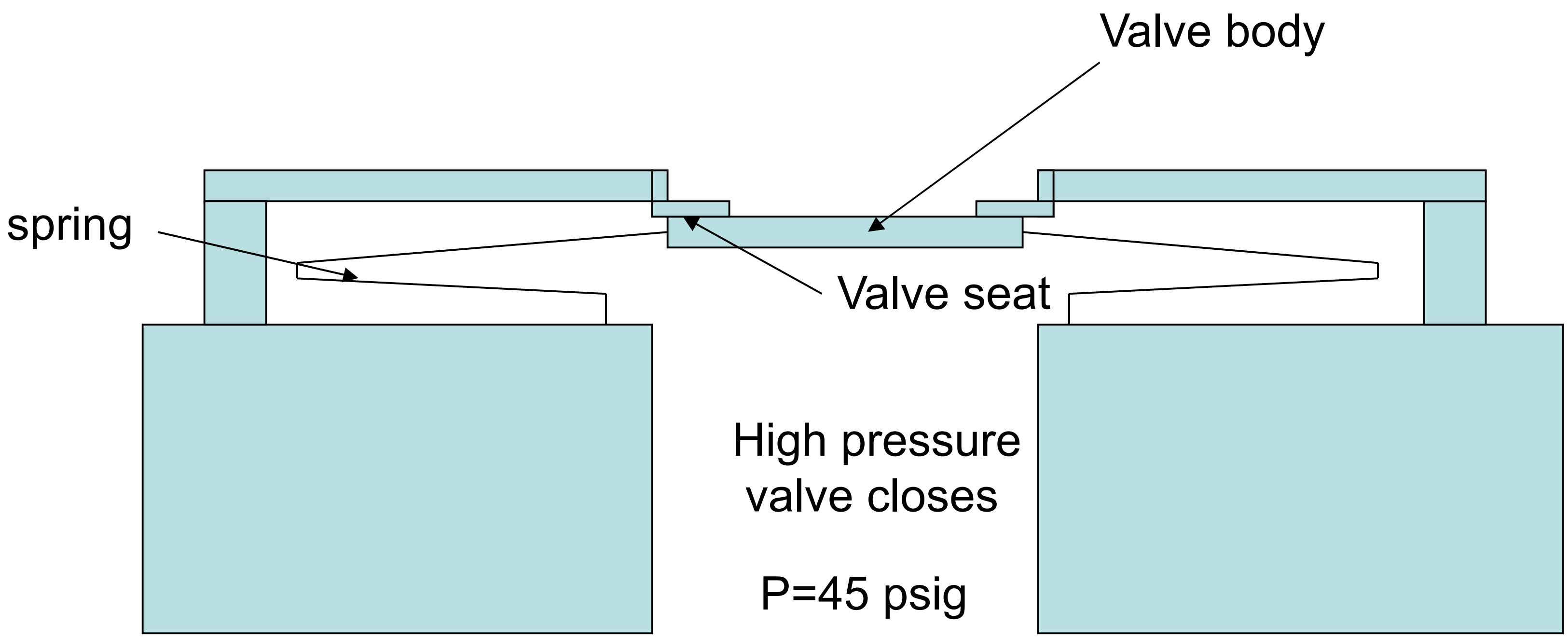


Figure 2 – Valve operating concept.

As-Fabricated Valve

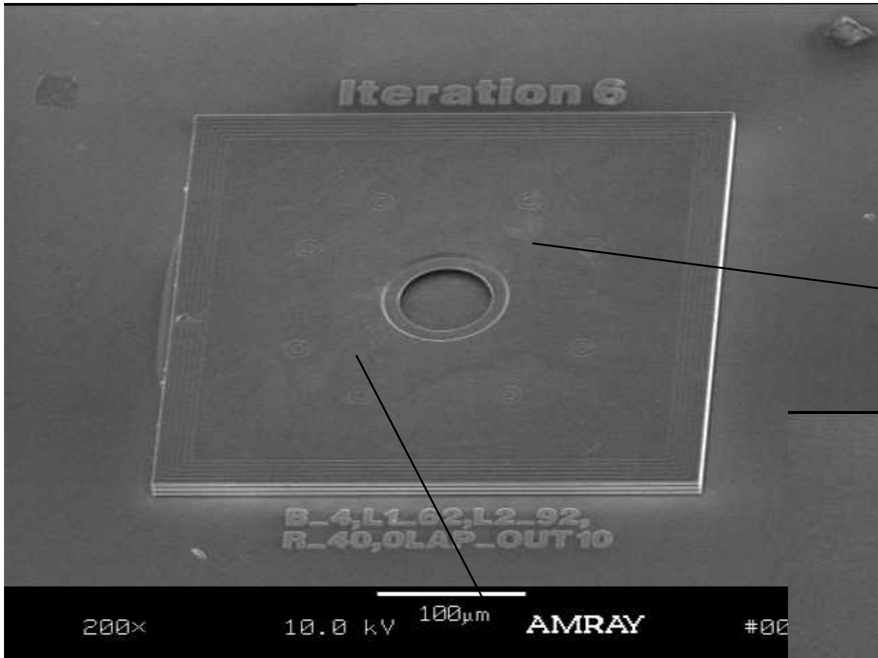
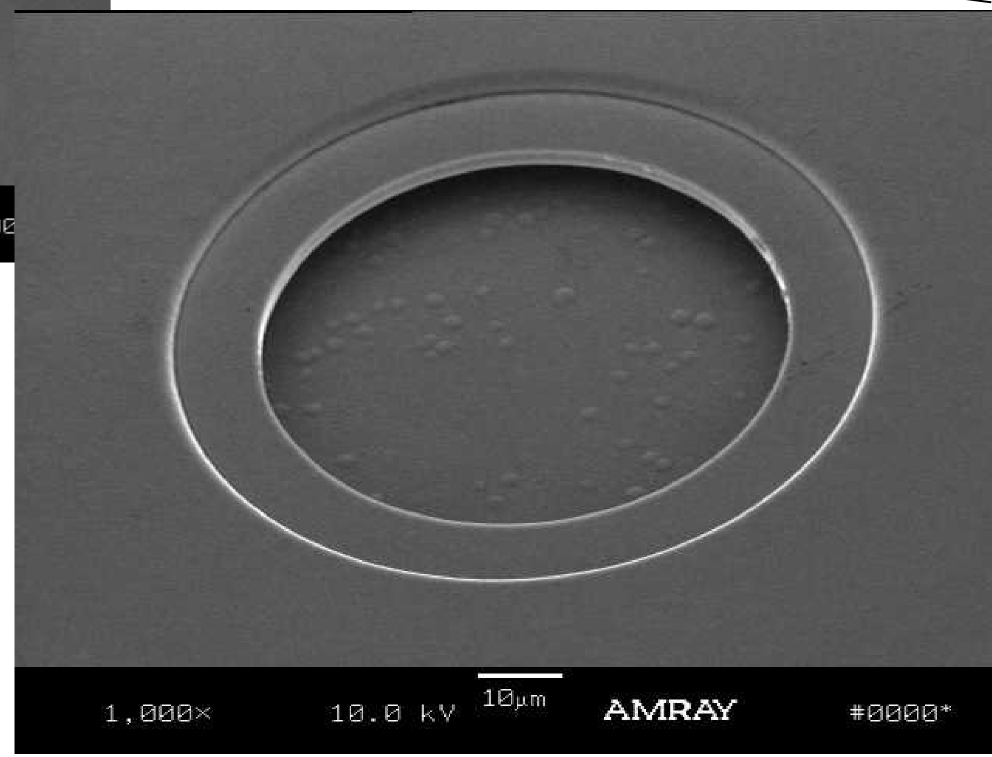


Figure 3a. As-Fabricated Valve



Cover removed to show springs

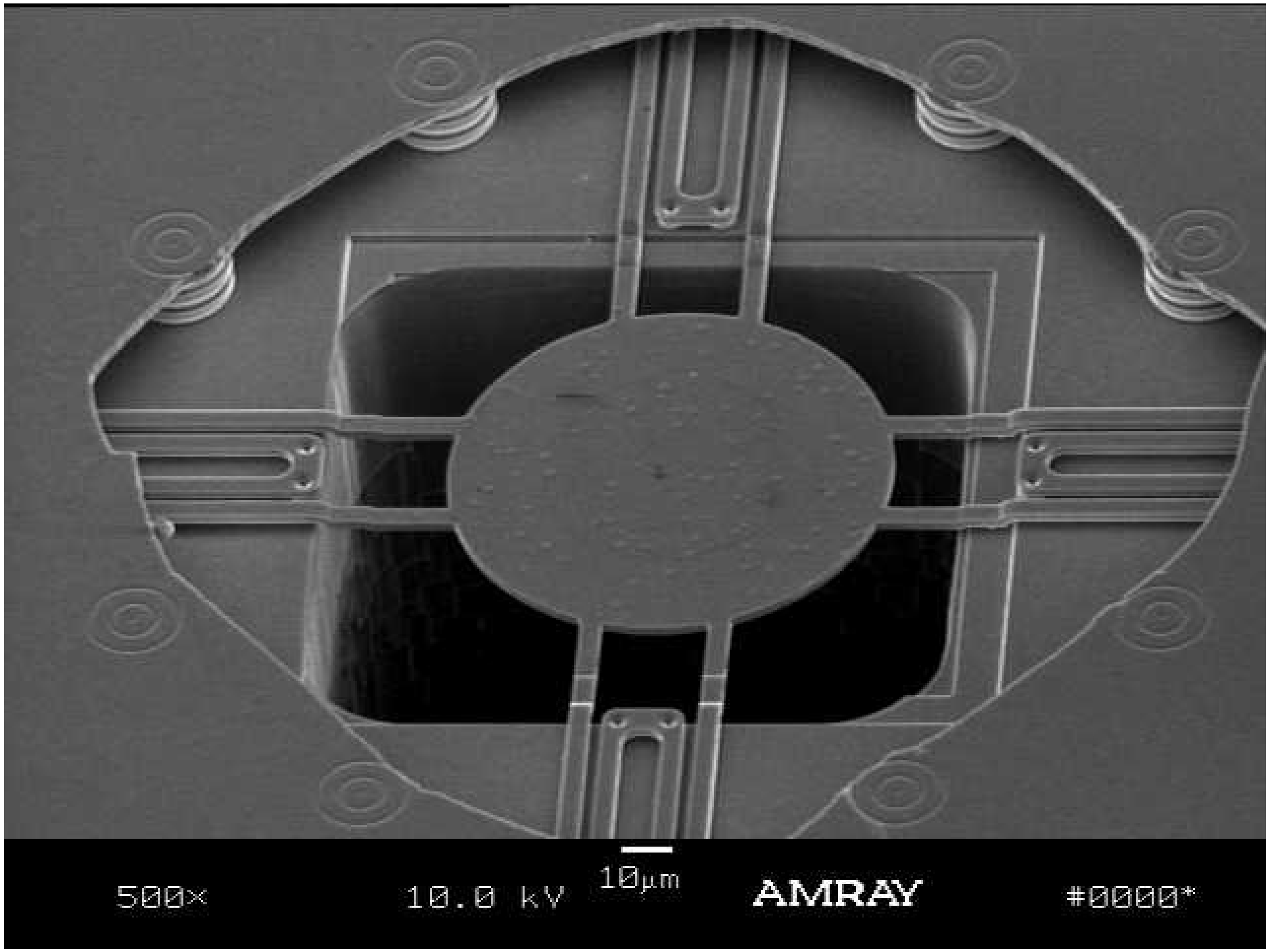


Figure 3b. As-fabricated valve – cover removed to show springs.

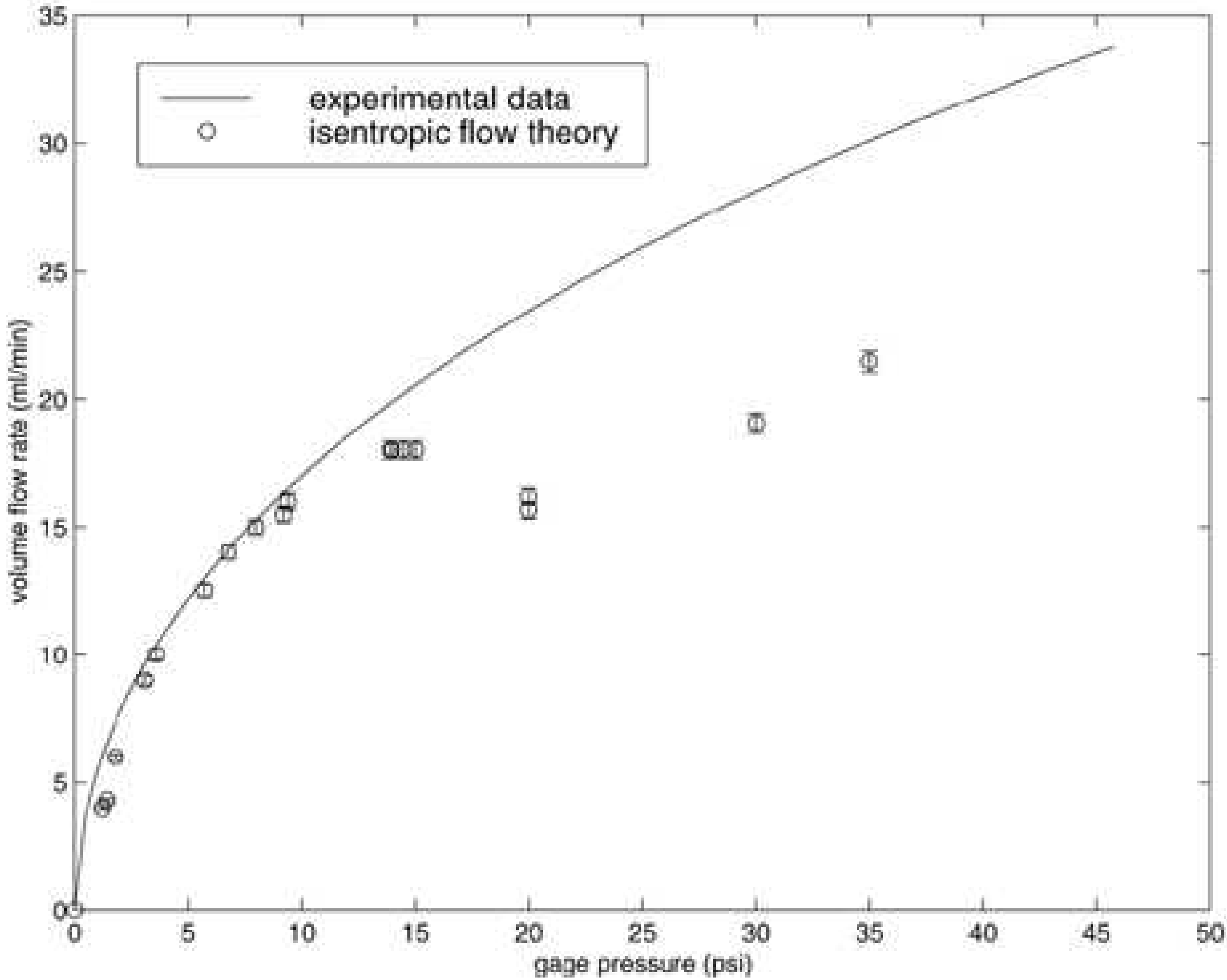


Figure 4. Orifice Flow Rate – 30 micron diameter orifice.

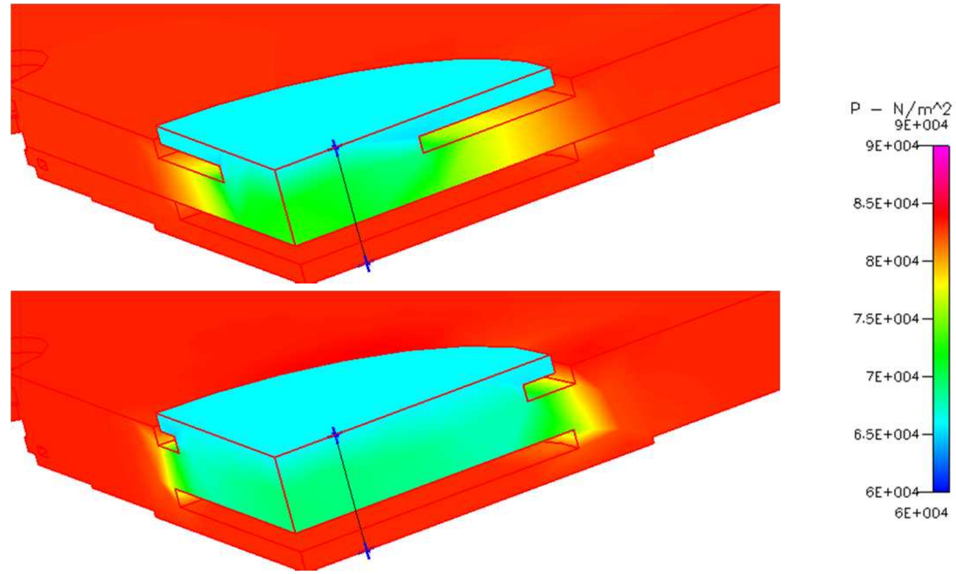
Simulations of 3 overlap conditions (2.5 psi):

3 μm overlap (P2-P4), 74 μm diameter hole in P4:
Flux through opening = 4.425×10^{-8} m^3/s
Flux times 4 = 1.8×10^{-7} m^3/s
Need ~ 6 valves in parallel to get 10^{-6} m^3/s = 60 ml/min

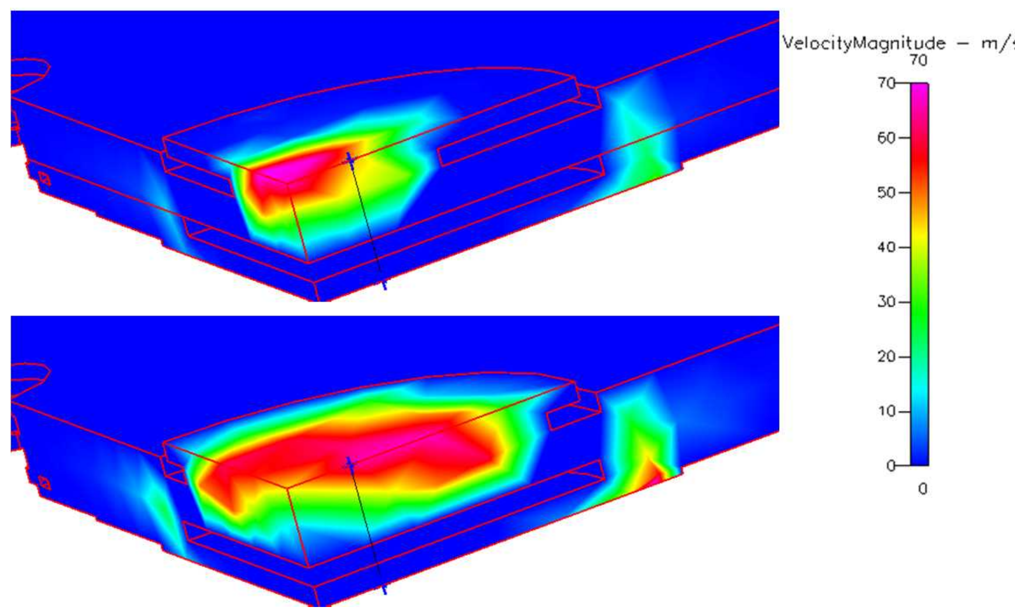
10 μm overlap (P2-P4), 60 μm diameter hole in P4:
Flux through opening = 2.8×10^{-8} m^3/s
Flux times 4 = 1.1×10^{-7} m^3/s
Need ~ 9 valves in parallel to get 10^{-6} m^3/s = 60 ml/min

20 μm overlap (P2-P4), 40 μm diameter hole in P4:
Flux through opening = 8.5×10^{-9} m^3/s
Flux times 4 = 3.4×10^{-8} m^3/s
Need ~ 30 valves in parallel to get 10^{-6} m^3/s = 60 ml/min

Pressure, 20 (top) vs 5 (bottom) micron overlap



Air Velocity, 20 (top) vs 5 (bottom) micron overlap:



CFD simulations (CFDRC) predict flow rates, local pressures and velocities for open valves.

- 3 μm overlap,37 μm radius – 10 ml/min/valve
- 10 μm overlap, 30 μm radius – 6.67 ml/min/valve
- 20 μm overlap, 20 μm radius – 2 ml/min/valve

Figure 5 – CFD figure

Spring Stiffness Table

Iteration	# springs	b(um)	L1(um)	L2(um)	orifice radius(um)	Keq(N/m)
1	2	4	80	80	40	38
2	2	2	70	100	40	14
3	2	4	50	80	60	61
4	2	4	70	100	40	29
5	2	8	50	80	60	125
6	4	4	62	92	40	77
7	4	4	45	75	40	152
8	4	4	62	92	50	77
9	4	8	75	105	50	101

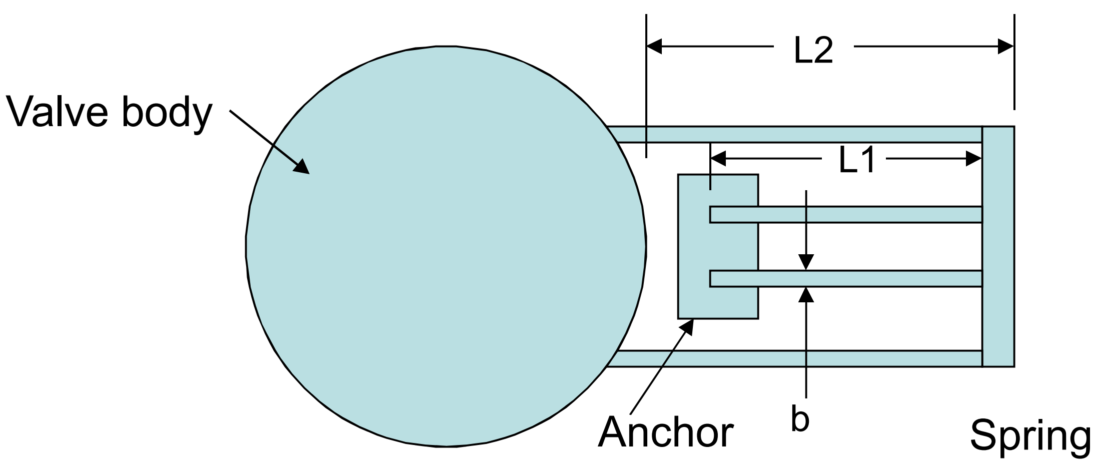
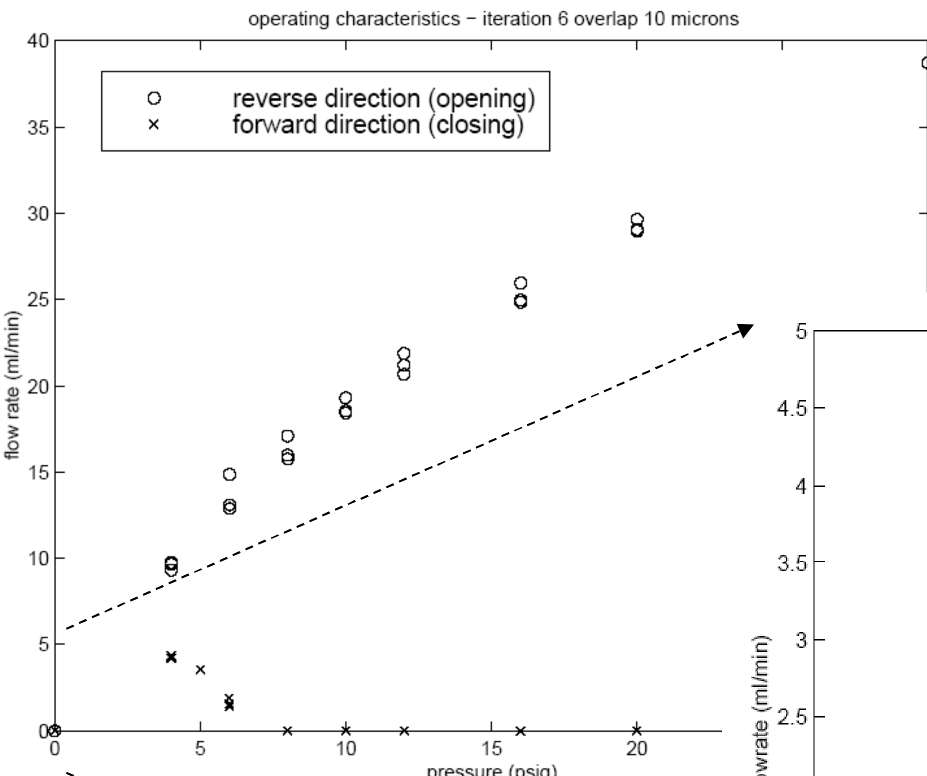


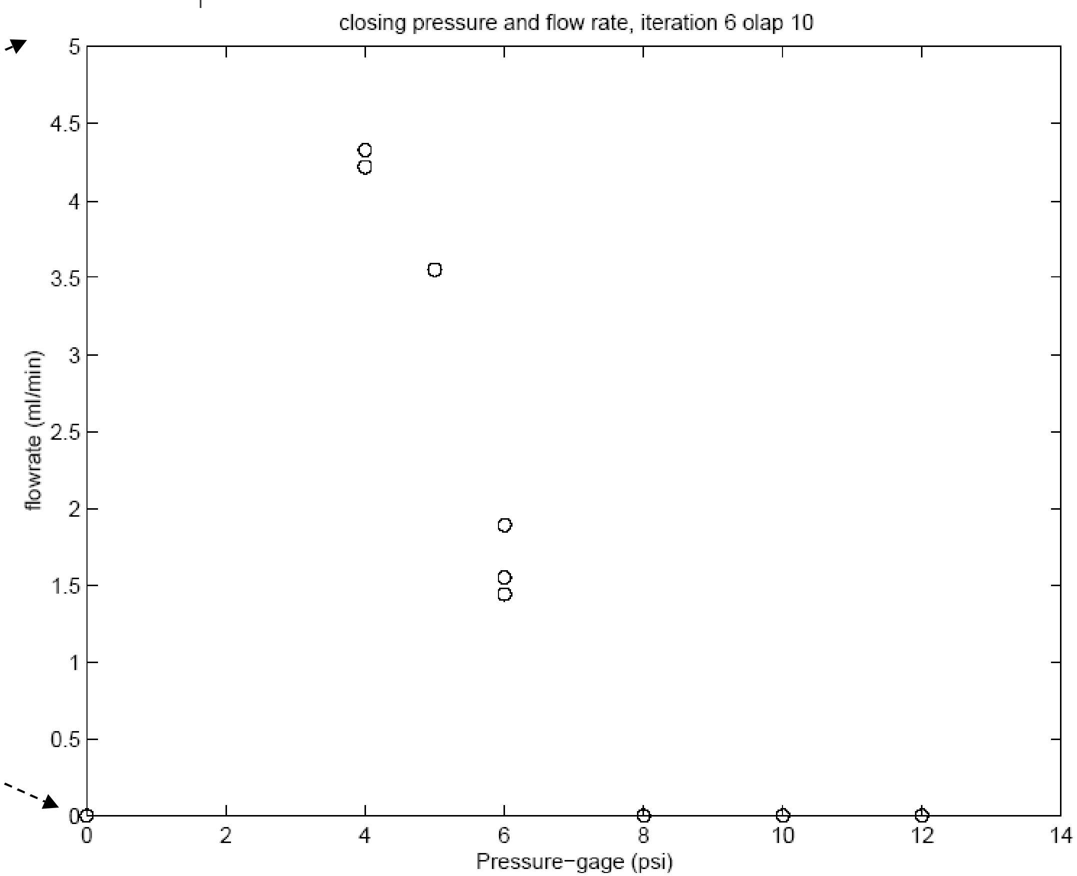
Table 2. Spring Stiffness

Test results (air) – typical curves – pressure vs flow

Valve iteration 6, olap 10

- K_{spring}= 77 μN/μm
- $R_{orifice}$= 40 μm





P_{close}= 8 psig

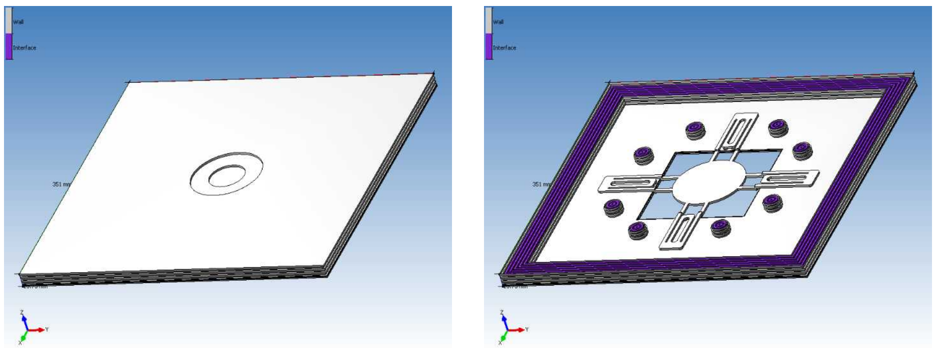
$Q_{low\ pressure}$= 4 ml/min (air), 4 psig

15 of these valves in parallel will deliver 60 ml/min

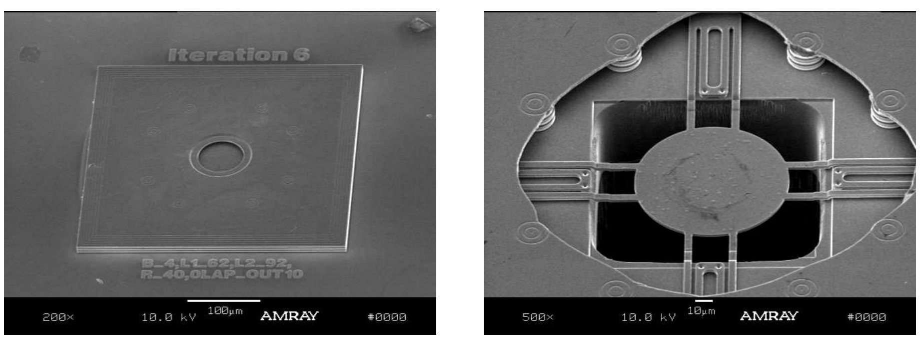
Figure 6. Forward vs. Reverse Flow

Figure 7. CFD comparison Passive MEMS Check Valve

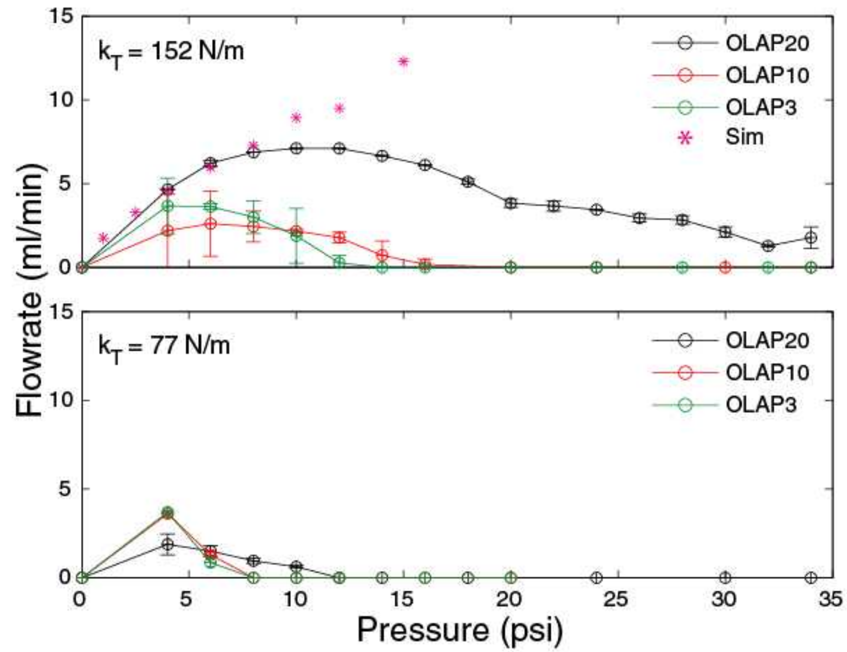
Designed a set of passive MEMS check valves for an internal customer. The SUMMIT V ™ valve remains fully open when pressurized below 5 psi, and fully closes when pressurized above a certain psi (varies for different designs). The flap seals against a surface micromachined lid on the front of the wafer. The footprint for a single valve is 0.35 mm x0.35 mm, and the maximum flowrate through one valve is ~4.5 ml/min at 5 psi.



Schematic design of a passive MEMS valve. On the right, the lid is removed to display the valve flap and springs. The inlet (through the wafer) is 125 μm wide and the outlet (through the front-side lid) is 40 μm wide.



SEM images of two valves. One valve lid is partially removed. The designed spring constant = 152 N/m. The valve is pressurized from the backside of the wafer, and the flap seals against the surface-micromachined lid.



Flowrate through two valve designs (spring constant, k_T = 152 and 77 N/m) as a function of pressure. OLAP3: 3 μm radial overlap between the lid and flap, producing a 74 μm diameter outlet; OLAP10: 10 μm overlap, 60 μm outlet; OLAP20: 20 μm overlap, 40 μm outlet.

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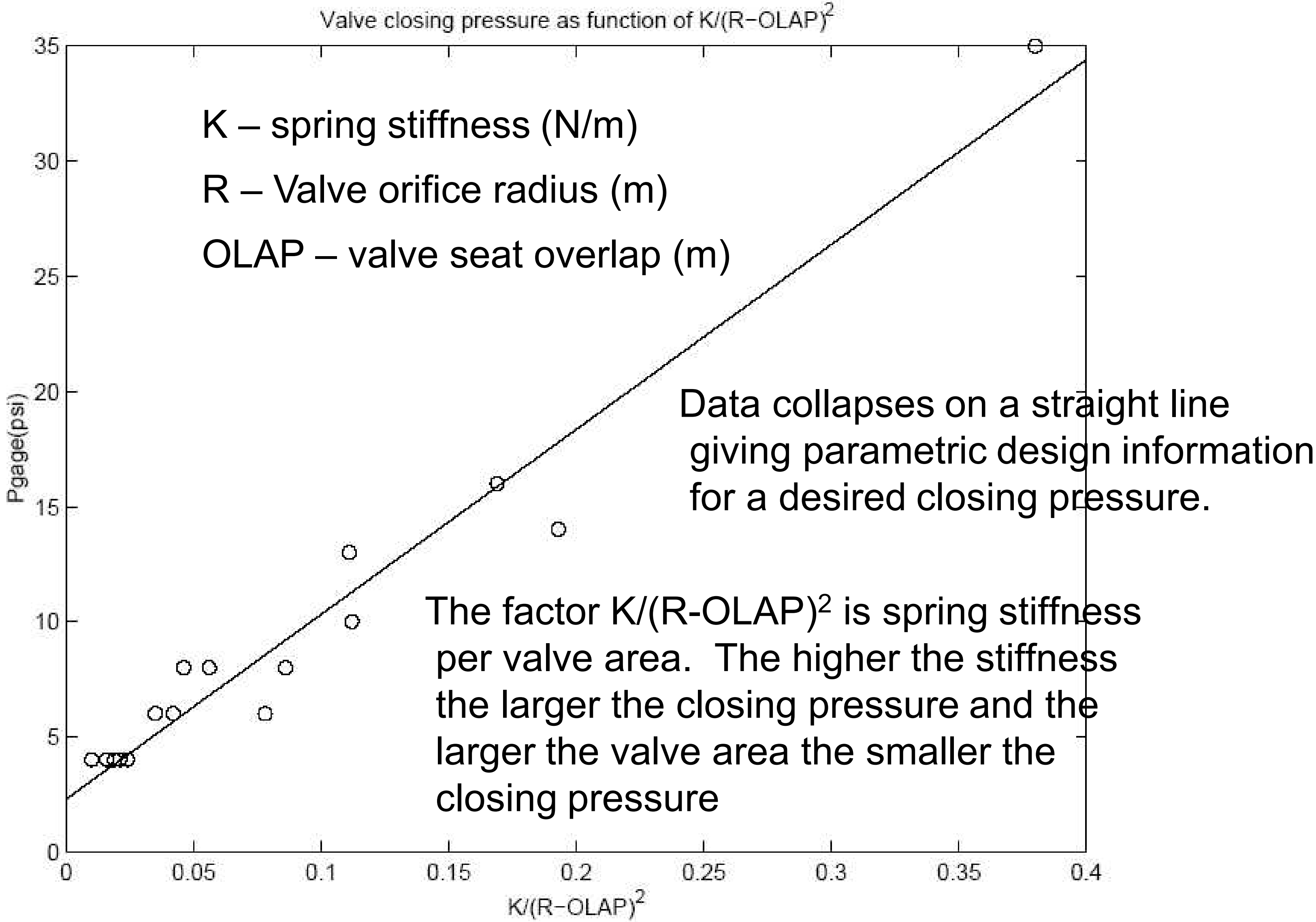
Figure 8. Closing pressure design curve



Measured Leak Rates

Figure 9. Leak Rates – as fabricated and epoxied lids

Device	Pressure(psi)	Leak (μl/sec)	epoxy lid leak (μl/sec)
4_olap3	15	2.5	
	30	1.3	
4_olap10	15	0.4, 0.5	0.1
	20	1.7	
	30	1.7, 2.2	0.7
	45		0.6
4_olap20	15	0.4	
	30	0.6	
5_olap10	15	0.4	
	30	0.1	
6_olap10	15	0.6	0.3
	30	1.0	0.6
	45		0.4
6_olap20	15	0.3	
	30	0.3	

Device 4 has R=40 microns, K=29 N/m
Device 5 has R=60 microns, K=125 N/m
Device 6 has R=40 microns, K=77 N/m

New design baseline is R=40 microns, K=152 N/m.

Epoxied (stiff) lid leak rates ½ to ¼ non-epoxied lid leak rates.

Images of Epoxied Lids – after 75 psi failure

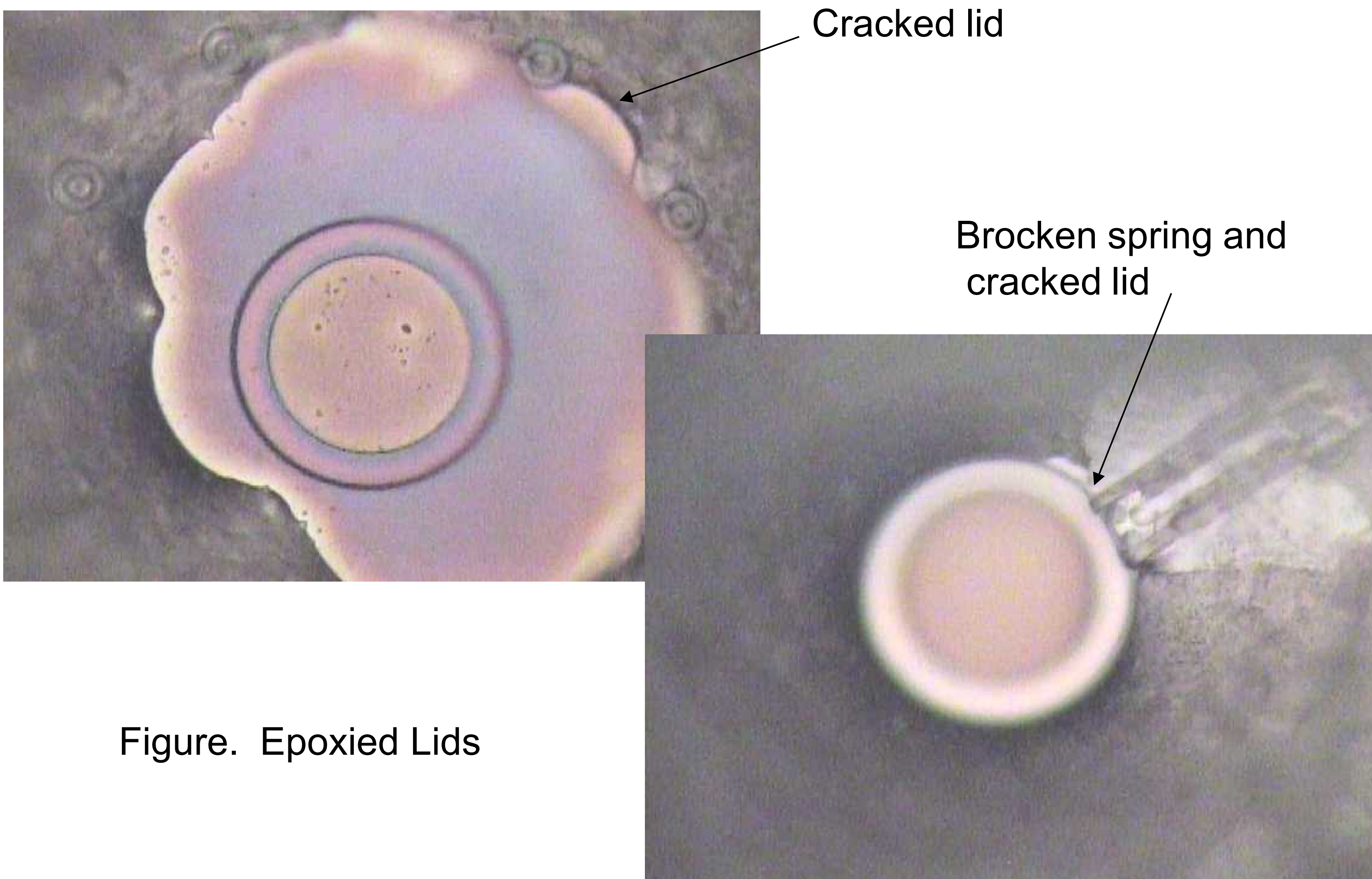


Figure. Epoxied Lids

Conclusions

- By careful design of valve spring constants a passive (no power required) one-way MEMS valve with a preset offset closing pressure can be fabricated. Offset pressures of 5 to 10 psi were demonstrated.
- Forward to reverse (leak with valve closed by pressure) flow ratio of (5 ml/min) / (0.018 ml/min) = 278 demonstrated.
- Future work on active (electrostatic) close against pressure valves will greatly increase application space for these valves (some power will be required).