Applied Microfluidics

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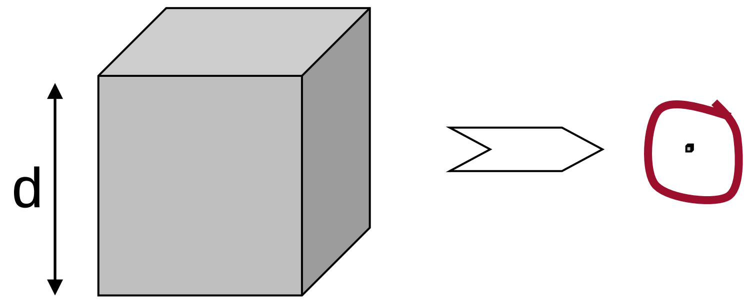
Why downscaling?

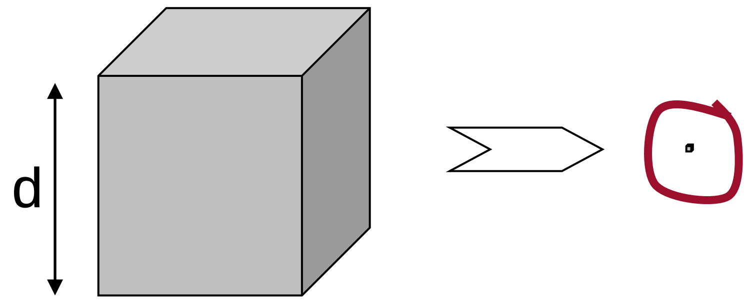


Volume V ~ d^3

Area A ~ d^2

Length L ~ d

Why downscaling?

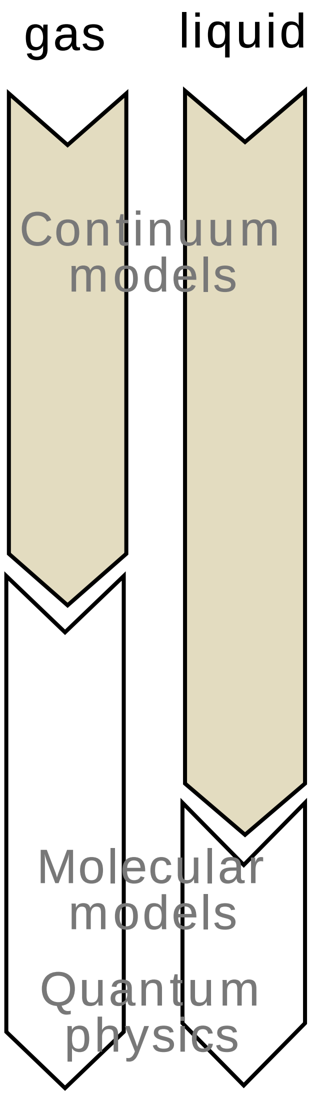


Volume V ~ d^3 ⇨ 1. Individual handling and manipulation of microscale objects in a liquid environment requires systems of the same magnitude order

Area A ~ d^2

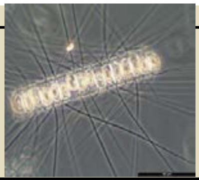
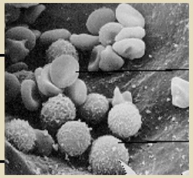
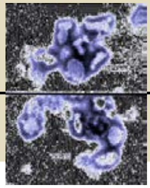
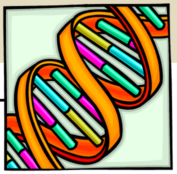
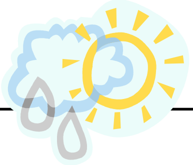
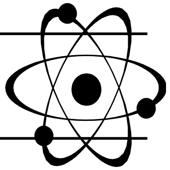
Length L ~ d

Small scale objects



Regime	Volume	Cube size	Objects
	1 ml=10^{-6} m^3	1 cm	"1 US teaspoon = 4.92892161 ml"
	1 µl =10^{-9} m^3	**1 mm**	**small insects, drizzle rain**
Microfluidics	**1 nl=10^{-12} m^3**	**0.1 mm**	**Human Ovarian cell; Fly poop; limit of the naked eye.**
Microfluidics	**1 pl=10^{-15} m^3**	**10 µm**	**Blood cells; spermatozoids**
Nanofluidics	**1 fl =10^{-18} m^3**	**1 µm**	**Bacteria; limit of light microscope**
Nanofluidics	1 al =10^{-21} m^3	0.1 µm	Virus, colloids, large DNA
Nanofluidics	1 zl =10^{-24} m^3	10 nm	carbon nano-tube; protein size; short DNA
Continuum breakdown	1 yl=10^{-27} m^3	1 nm	raindrop nucleation
	1 xl=10^{-30} m^3	1 Å	Small molecules



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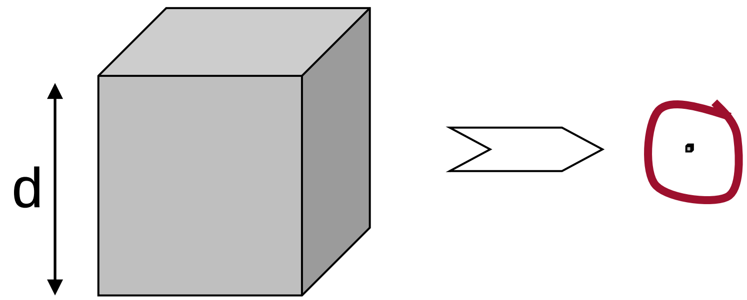
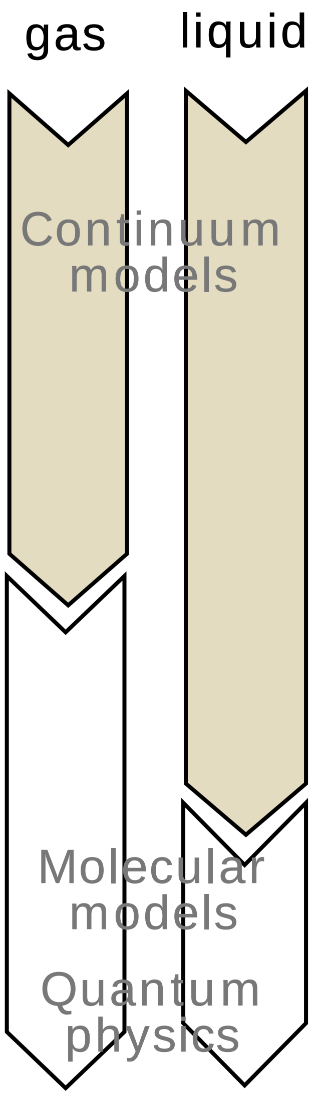


Volume V ~ d^3 ⇨ 2. Handling and manipulation of very small sample volumes (<10 µl) requires system features of the same magnitude order

Area A ~ d^2

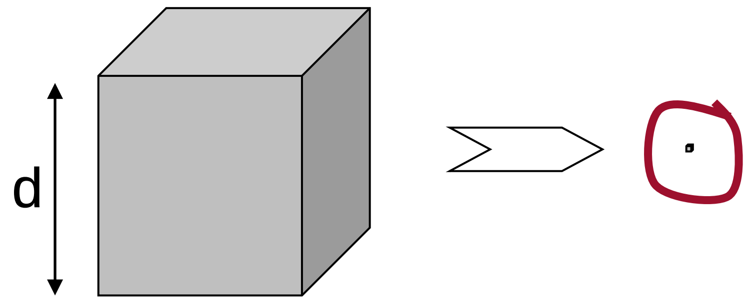
Length L ~ d

Small Volumes



Regime	Volume	Cube size	
	1 ml=10^{-6} m^3	1 cm	
Microfluidics	**1 µl =10^{-9} m^3**	**1 mm**	Smallest pipettes dispense ~0.5µL
Microfluidics	**1 nl=10^{-12} m^3**	**0.1 mm**	Inkjet print droplets ~50 pL
Microfluidics	**1 pl=10^{-15} m^3**	**10 µm**	
Nanofluidics	**1 fl =10^{-18} m^3**	**1 µm**	
Nanofluidics	1 al =10^{-21} m^3	0.1 µm	
Nanofluidics	1 zl =10^{-24} m^3	10 nm	
Continuum breakdown	1 yl=10^{-27} m^3	1 nm	
Continuum breakdown	1 xl=10^{-30} m^3	1 Å	

Why downscaling?



Volume V ~ d^3

Area A ~ d^2

Length L ~ d

Downscaling leads to an increased area per volume:

A/V ~ 1/d

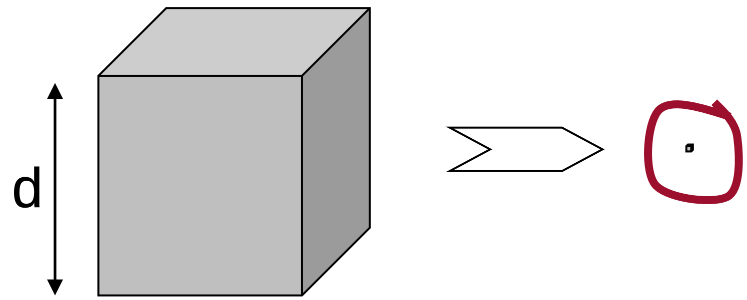
⇩

Surface related physical effects become dominant in the microscale

Examples of surface related effects in fluidics

- Friction at the liquid-solid boundary:
  - Zero slip at the wall results in laminar flow
- Electro-fluidic interaction:
  - Electric double layer related phenomena:
    - Electro-osmotic flow
    - Electro-viscous effect
    - …

Why downscaling?



Volume V ~ d^3

Area A ~ d^2

Length L ~ d

Diffusion becomes a transport phenomenon of importance

Diffusion as a transport mechanism

- Diffusion is described by Fick's first and second law (see Wikipedia for more information).

Diffusion length: L_D; Diffusion constant: D; time: t

$$L_D \approx 2\sqrt{D \cdot t}$$

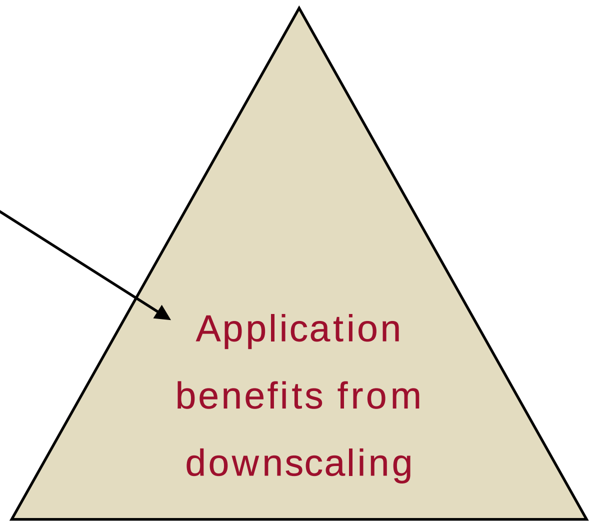
Molecule in H_2O	Typical D	L_D for 1 s	L_D for 100 s
N_2	1e-6	2 mm	20 mm
Protein (100 kDa; 5 nm diameter)	1e-10	20 µm	200 µm

Why downscaling (fluidic) components?

Application demands small size

- Monitoring in confined spaces (human body)
- Handling small volumes (DNA, cells, inkjet drops)
- Portability
- Functional integration
- ...

Application does not benefit from downscaling



Large surface / volume ration

Low inertia

Microfabrication technology:
- Semiconductor manufacturing
- Polymer microreplication

Increased performance

- Fast response
- Large spatial gradient
- Surface effects
- Precision
- ...

Decreased cost

- Manufacturing cost
- Materials cost
- Consumables reduction (high-throughput screening)
- ...

Lecture outline

- Classification of microfluidic components and systems
- Gas microvalves
- Inkjet printheads
- Micropumps
- Power-MEMS
  - Fuel cells
  - Microcombustion systems
- Examples of commercially available multifunctional microfluidic platforms
  - PDMS based fluidic microfluidic platforms
  - CD-based microfluidic platforms
- Microfluidic solutions for diagnostic devices
- Micro-macro fluidic interfaces
  - Nebulisers
  - ESI tips

Bubblejet printhead principle

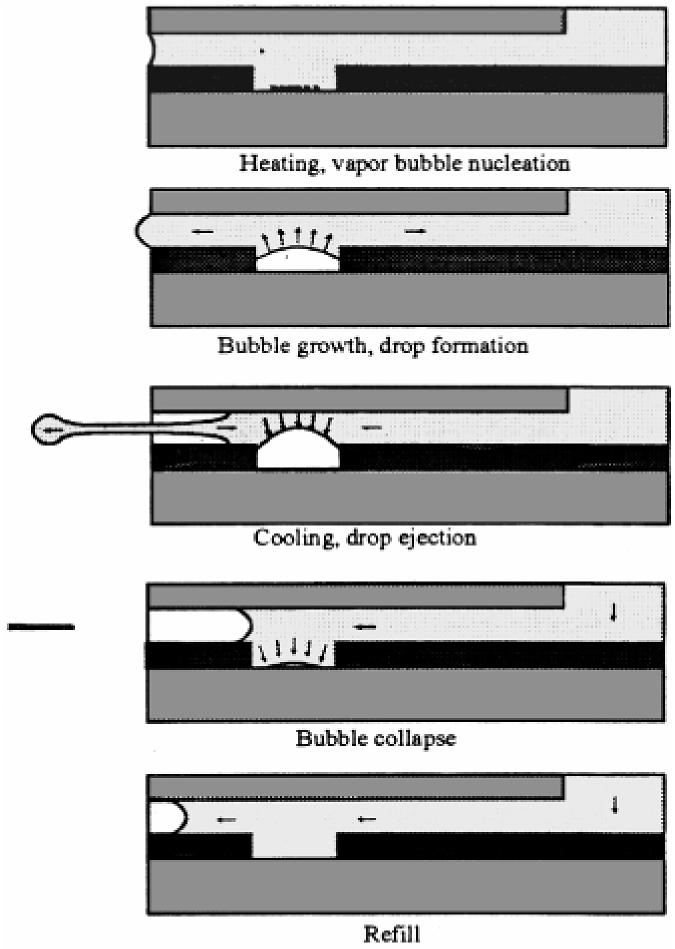


Figure 3: Generic TIJ drop ejection cycle.

Some typical figures:

- heater temp: 400°C
- drop velocity: 10 m/s
- drop volume: 100 pl
- pressure range:
  - bubble growth:10 - 40 atm
  - bubble collapse: 100 atm
- cycle frequency: 1 - 10 kHz

Inkjet printheads - Examples

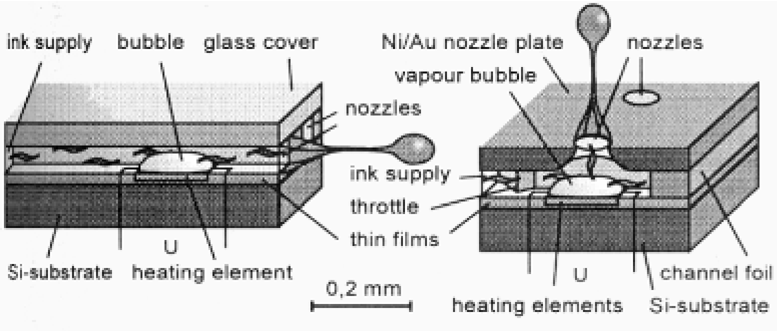


Figure 1. Bubble-jet principles (left Edgeshooter, right Sideshooter)

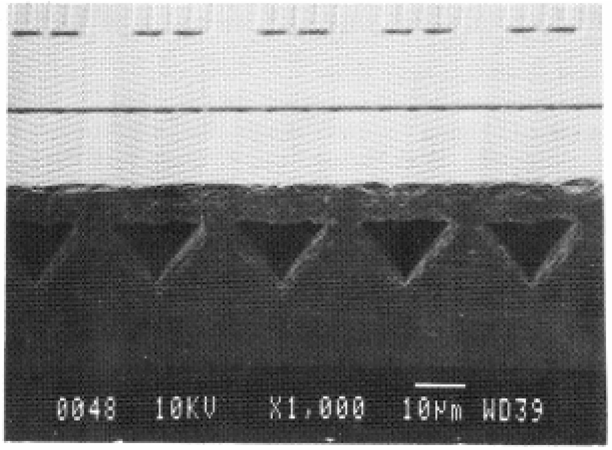
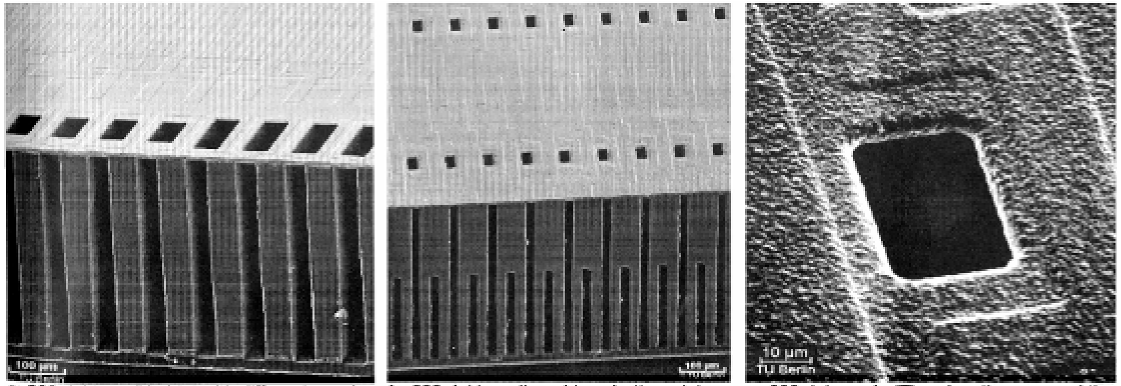


Fig. 4: Close-up of the nozzle array. At the rear of each microchannel is the integrated polysilicon heater.



a: 300 dpi type (Variant with different nozzle dimensions)

b: 600 dpi type (to achieve better print quality, direct neighbouring channels are shifted)

c: 600 dpi nozzle (The elevations around the nozzle are caused by Al-leads)

Figure 6. Cross sectional SEM-images of Backshooter microsystems.

Inkjet Printers – Monolythic system integration

Need for large data handling requires high level of integration !

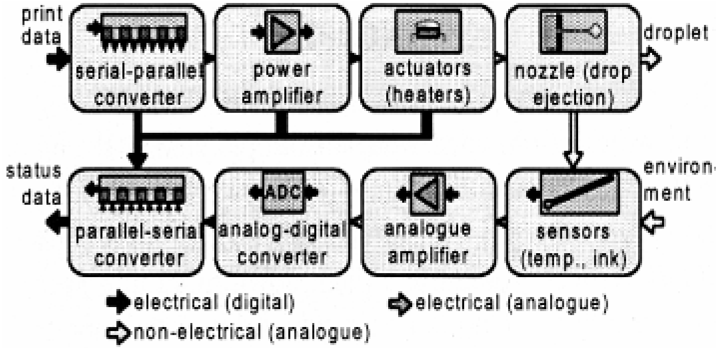


Figure 3. Material and signal flow in the Backshooter microsystem inkjet printhead

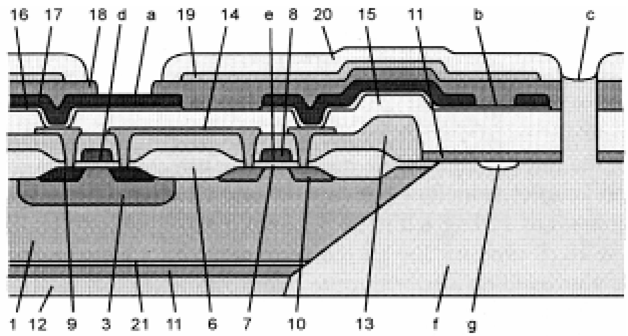


Figure 4. Structure of the Backshooter microsystem inkjet printhead (not true to scale) ***Layers:*** *(1) Substrate (<110>-silicon); (11) etch stop layer (LPCVD-Si_3N_4); (12)PECVD-SiO_2; (13)BPSG; (14) 1. metal layer(Al); (15) undoped silicate glass (USG); (16) heater layer (HfB_2); (17) 2. metal layer (Al); (18) thermal throttle layer (PECVD-Si_3N_4); (19) galvanic adhesive layers (Ti / Cu); (20) carrier layer (Ni / Au); (21) thermal SiO_2.* ***Elements:*** *(a) bond pad (Al); (b) heating element (HfB_2); (c) nozzle; (d) PMOS transistor; (e) NMOS transistor; (f) ink chamber / ink; (g) vapour bubble*

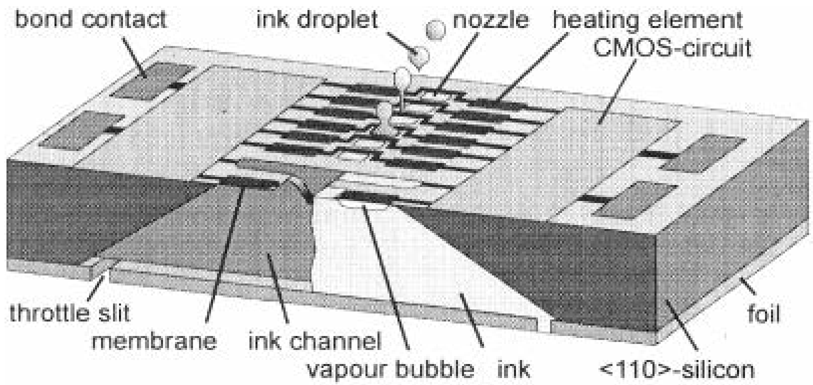


Figure 2. Schematic Backshooter printhead (filled half with ink)

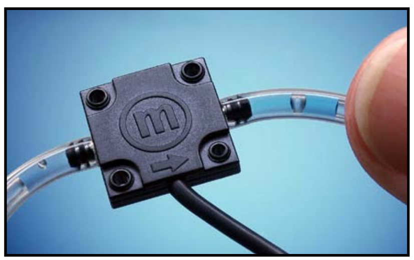
Group discussion

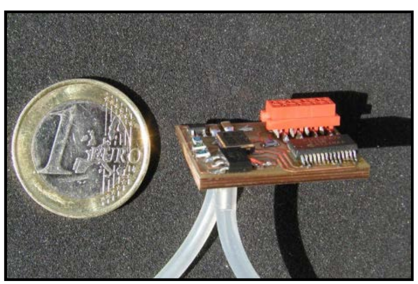
- What limits the amount of pages/minute that a bubble jet printer can produce?
- -
- -
- -
- …

Lecture outline

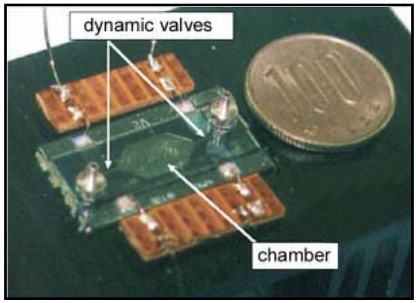
- Classification of microfluidic components and systems
- Gas microvalves
- Inkjet printheads
- Micropumps
- Power-MEMS
  - Fuel cells
  - Microcombustion systems
- Examples of commercially available multifunctional microfluidic platforms
  - PDMS based fluidic microfluidic platforms
  - CD-based microfluidic platforms
- Microfluidic solutions for diagnostic devices
- Micro-macro fluidic interfaces
  - Nebulisers
  - ESI tips

Micropumps – a classification





- **displacement**
  - **reciprocating**
    - **diaphragm**
      - *drivers*
        - piezoelectric
          - lateral
          - axial
        - thermopneumatic
        - electrostatic
        - pneumatic
      - *valves*
        - flap
        - fixed-geometry
          - nozzle-diffuser
          - Tesla
      - *chambers*
        - single
        - multiple/series (peristaltic)
        - multiple/parallel
    - **piston**
  - **rotary**
  - **aperiodic**
    - pneumatic
    - phase change
      - thermal
      - electrochemical
    - electrowetting/thermocapillary
- **dynamic**
  - **centrifugal**
  - **electrohydrodynamic**
    - injection
    - induction
    - conduction
  - **electroosmotic**
    - porous
    - micromachined
  - **magnetohydrodynamic**
    - DC
    - AC
  - **acoustic streaming/ultrasonic**
  - **miscellaneous special effect**
    - jet
    - gas lift
    - hydraulic ram



[Krutzch et al.]

Micropump applications

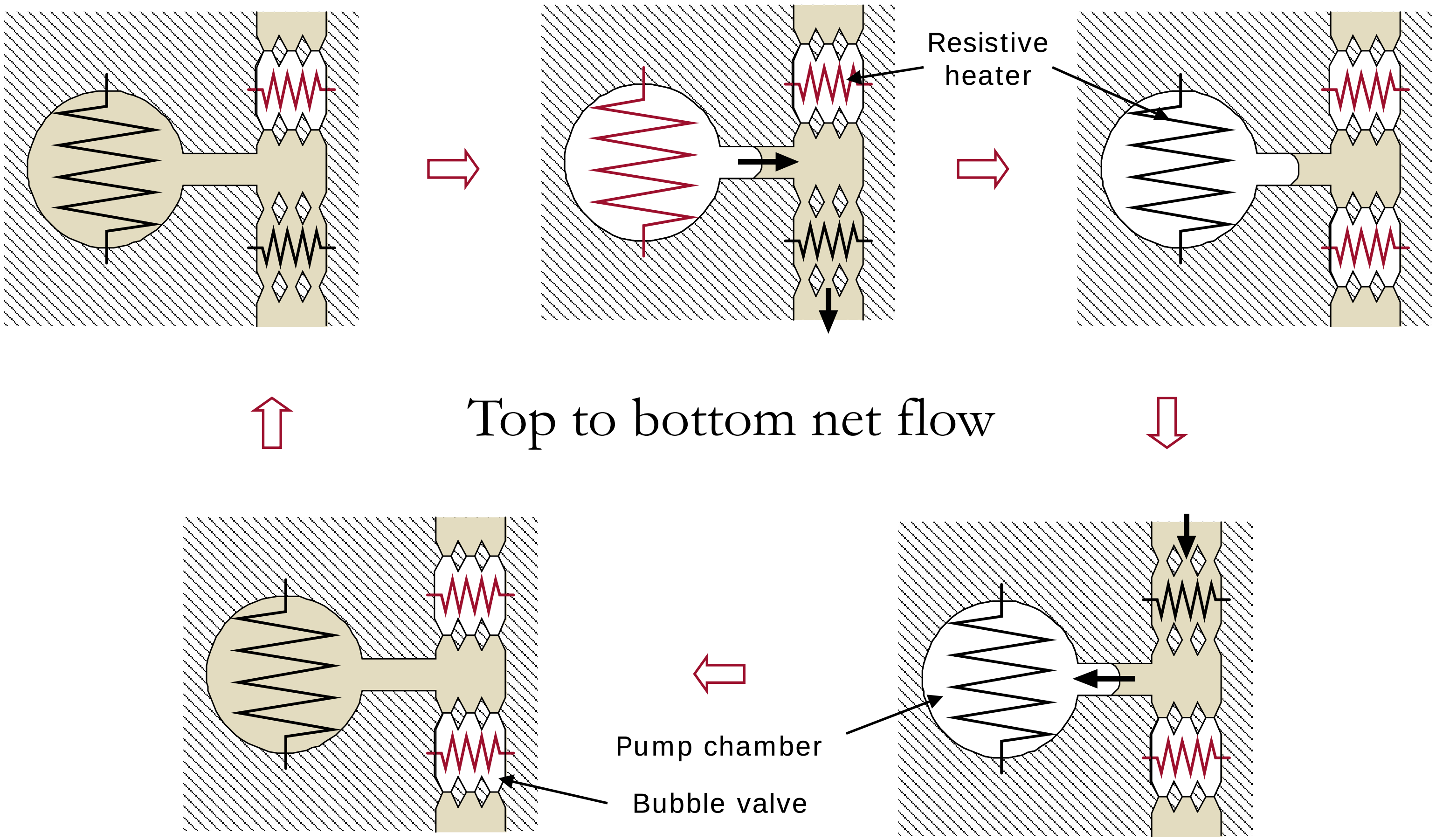
- The following is a non-exhaustive list of used and suggested applications:
  - Drug delivery (transdermal or implanted)
  - Fuel pump (Fuel cells)
  - Miniaturised diagnostic systems (Lab on a chip)
  - Space exploration:
    - – miniaturised instrumentation
    - – propulsion
  - IC cooling
  - …

Required characteristics

Precision

Flow rate

Bubble valve pump



Freely adapted from [A planar laminar mixer, Evans et al, Berkeley]

Hydrolysis as actuator

- positive current dissociates the water
  → gas bubbles push out the liquid
- Negative current reduces the gas
  → liquid is sucked back
- 3 electrodes:
  - 2 used for actuation (red, green)
  - 2 used for conductivity measurement (green, blue)

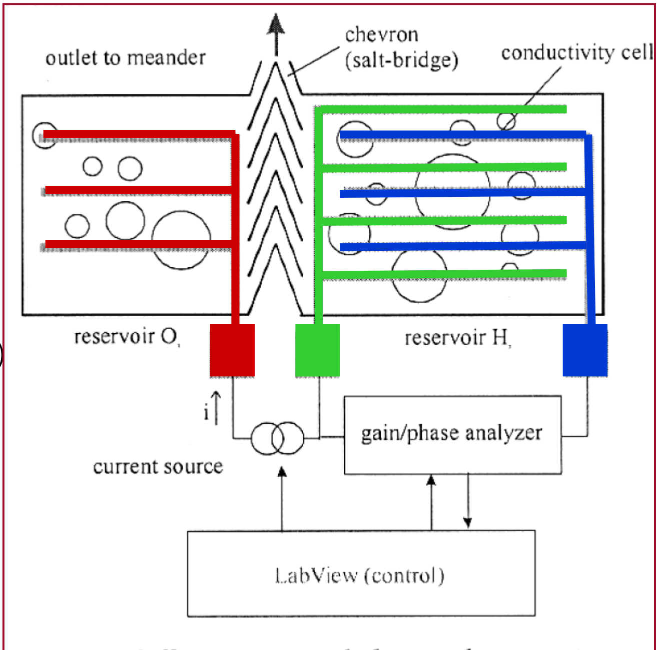


Figure 3: Cell geometry and electrical connection.

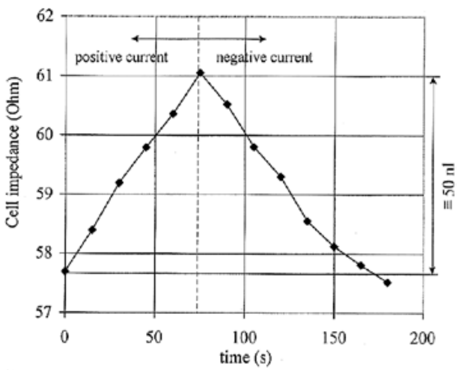
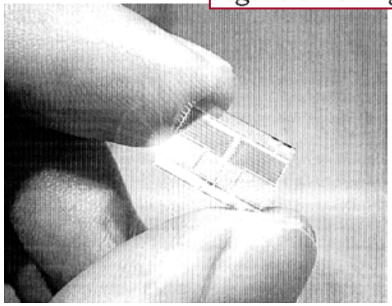
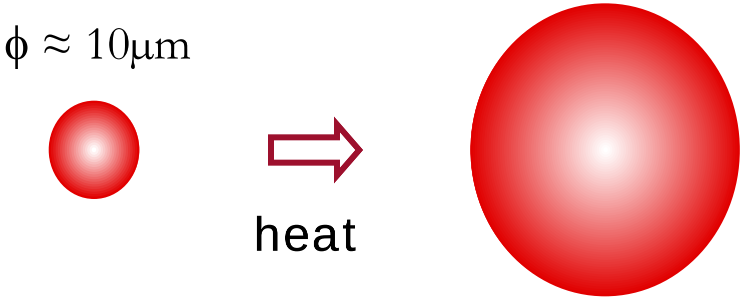


Figure 6: Drawing dispensed liquid back into the meander by current reversal. In the first phase (t<70 s) 50 nl is dispensed and drawn back in the second phase.



[Böhm et al, Utwente, The Netherlands]

Expandable bead actuators



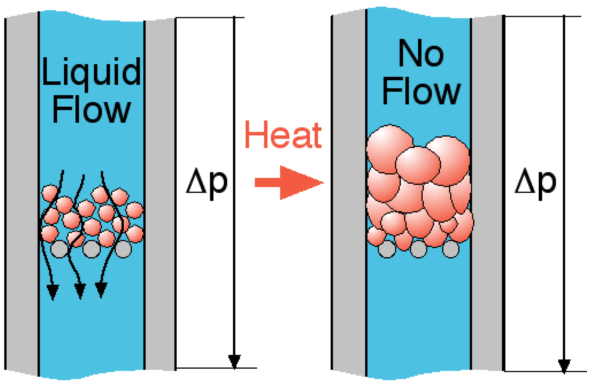
V_0

Initial volume

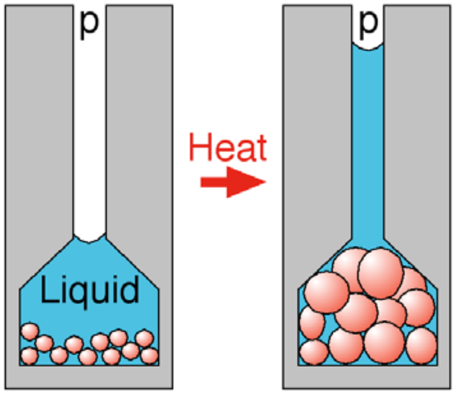
$\sim 60V_0$

Expanded volume

[Griss et al, KTH-S3]



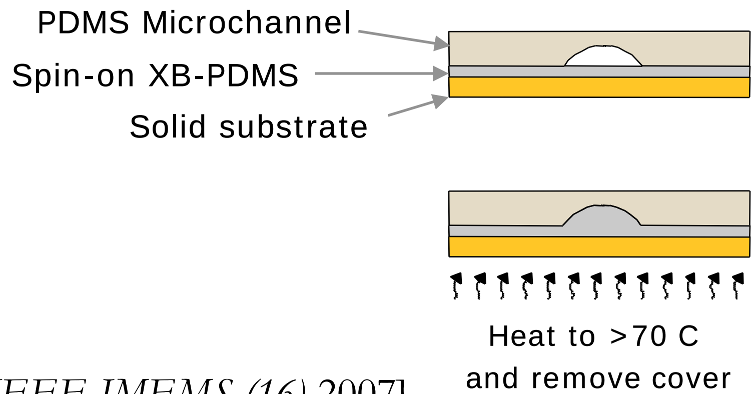
One-shot valve

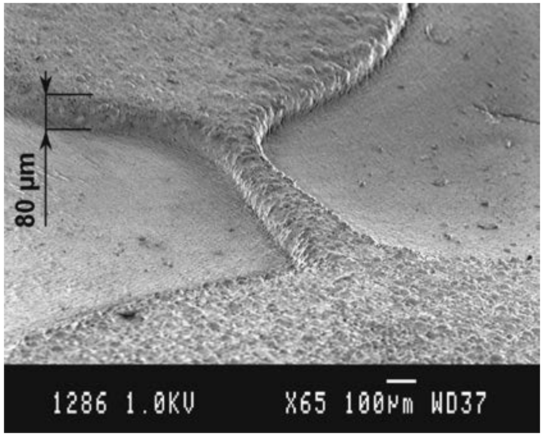


One-shot pump

Expandable microspheres in PDMS

- Mixing PDMS and Expancel® microspheres: XB-PDMS
  → A thermally responsive PDMS composite
  - Large expansion (> 100%)
  - Highly elastomeric
  - Non-toxic and chemically inert
  - Allows for e.g. soft lithography, casting, spinning…
  - Highly integratable actuator

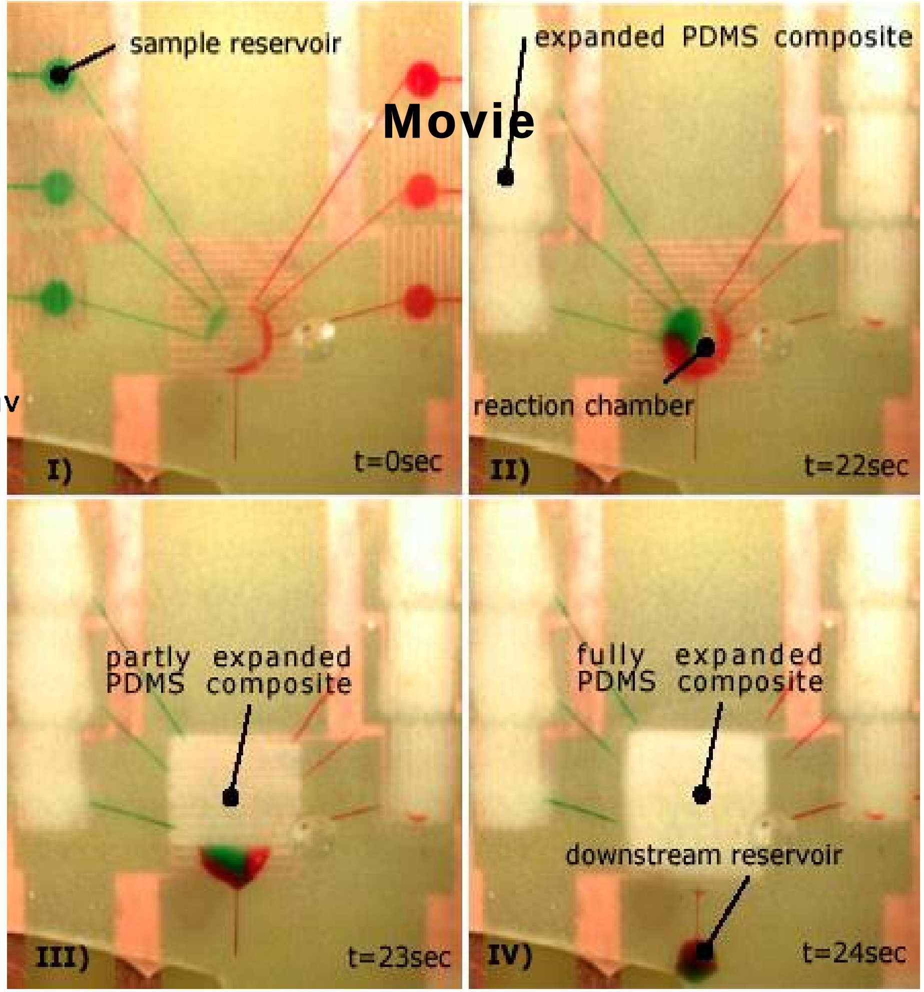




[Samel et al., *IEEE JMEMS (16)* 2007]

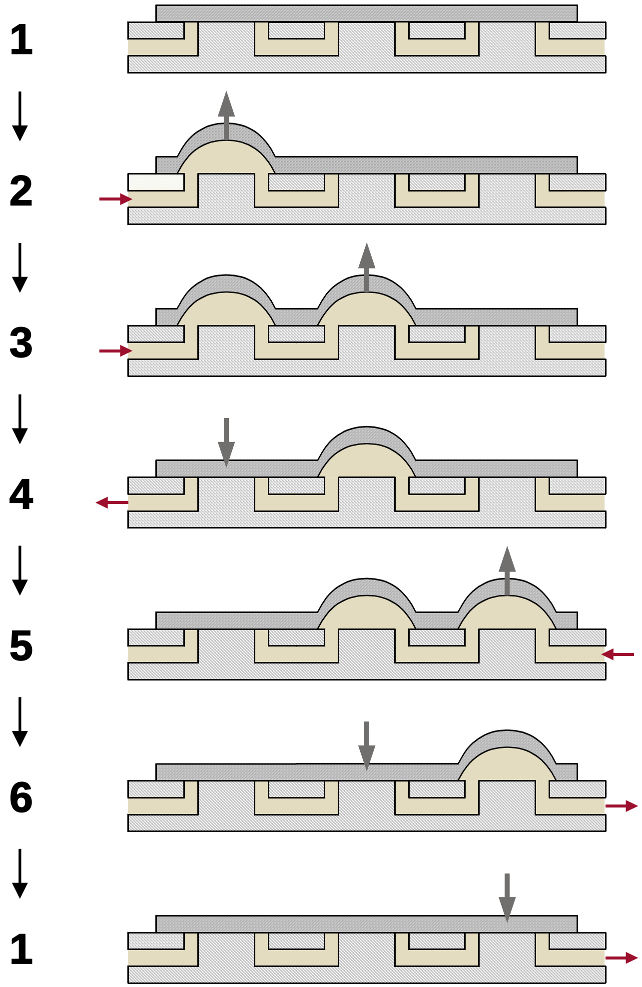
Expandable bead pumps

dose_transport_merge_short.wmv



[B. Samel et al., KTH]

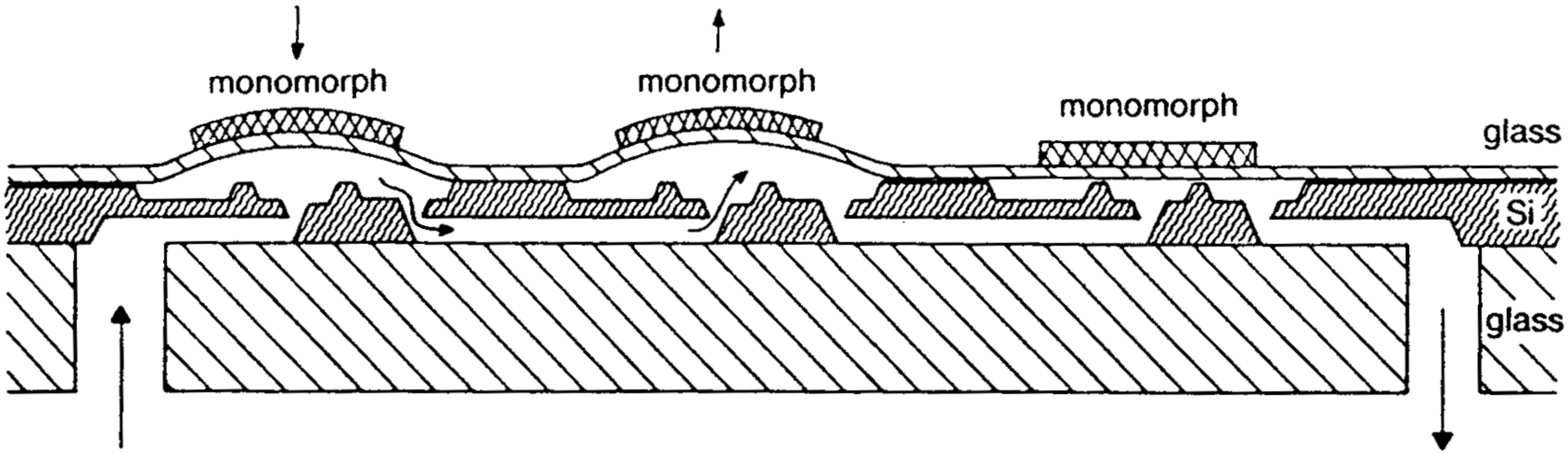
Peristaltic pump principle



Other examples of peristaltic movements in nature:

- Movement of worms and larves
- Intestines pressing through food

A peristaltic micropump example

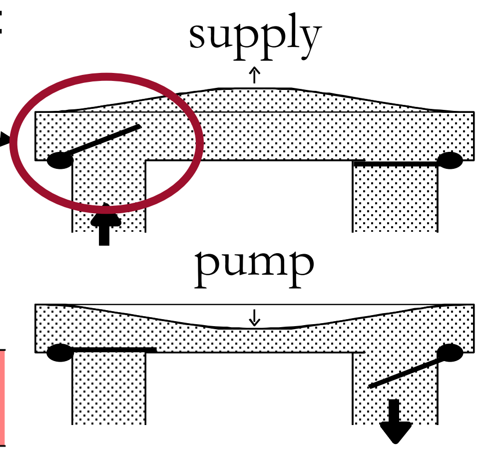


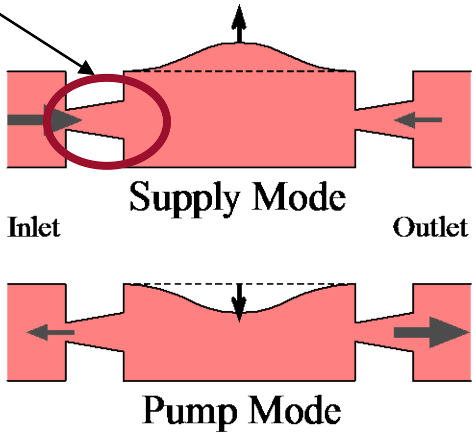
J. G. Smits, “Piezoelectric Micropump with Three Valves Working Peristaltically,” *Sensors and Actuators*, vol. A21-A23 (1990) 203-206.

Reciprocating Pumps

A pump consisting of:

1. One pressure chamber enabling volume displacement (with at one side most often a diaphragm actuator);
2. Flow directing elements at the inlet and outlet:
   - Mechanical valve
   - Diffuser
   - Nozzle
   - Tesla valve
   - ...





Passive mechanical microvalves

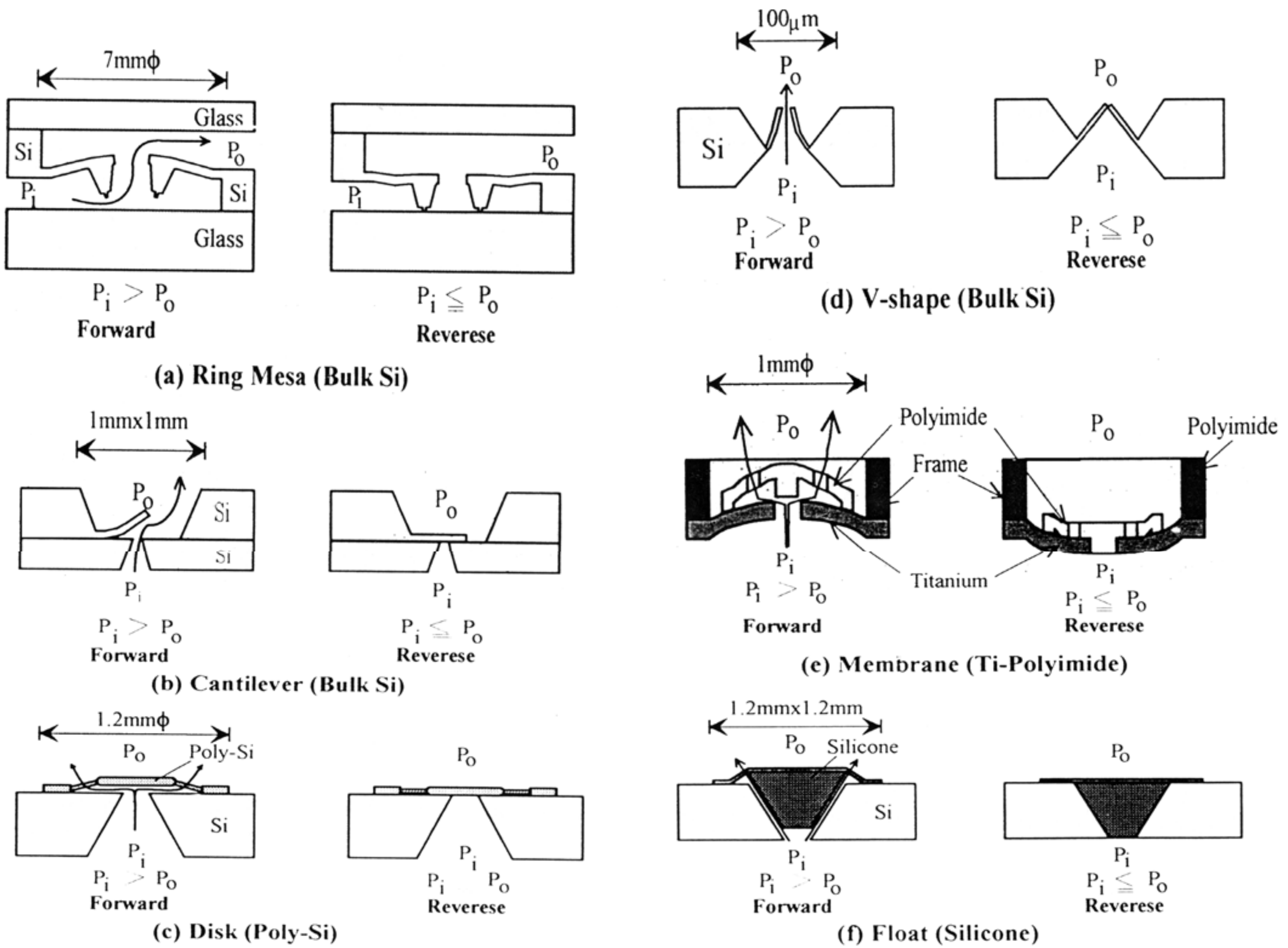
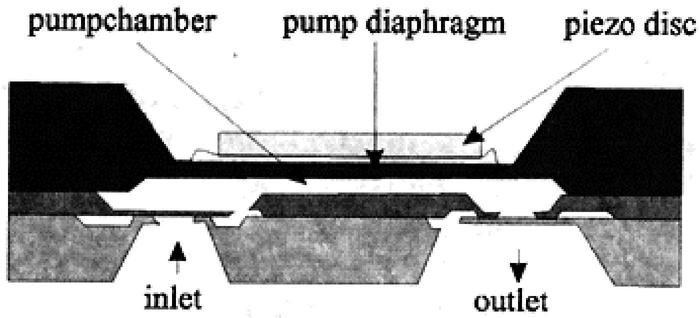


Figure 14. Schematics of the microcheck valves (passive microvalves).

[Shoji et al., Microflow devices and systems, JMM 4 (1994), pp. 157-171]

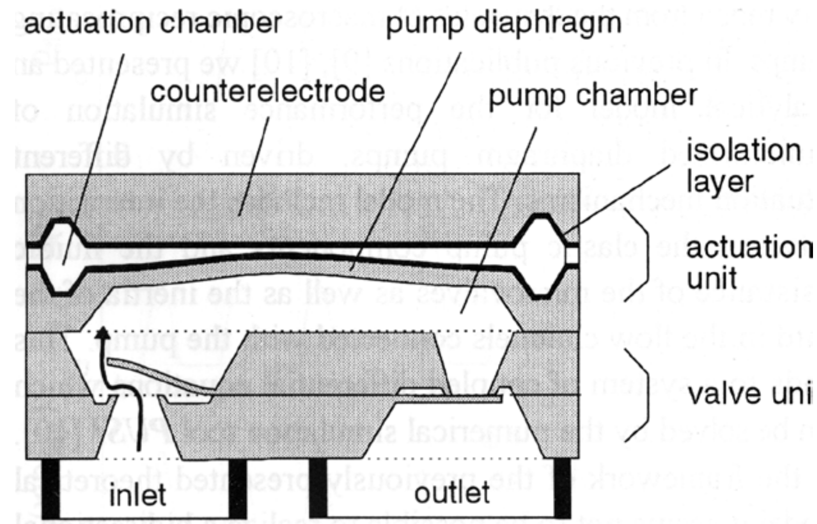
Reciprocating passive valve micropump

Piezoelectrically actuated flap valve micropump

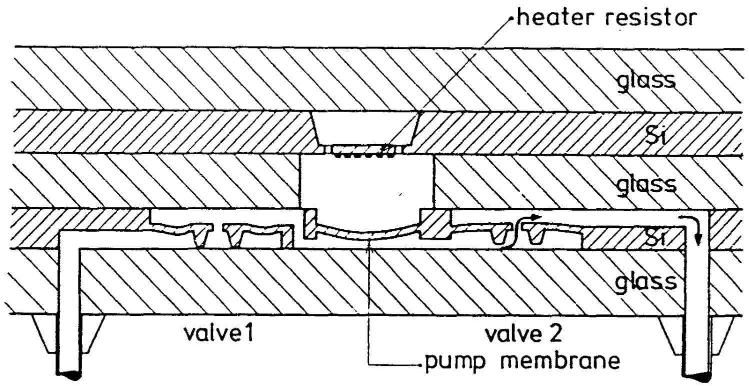


[R. Linneman et al., MEMS'98, Heidelberg]

Electrostatically actuated flap valve micropump



[R. Zengerle et al., MEMS'95, Amsterdam]



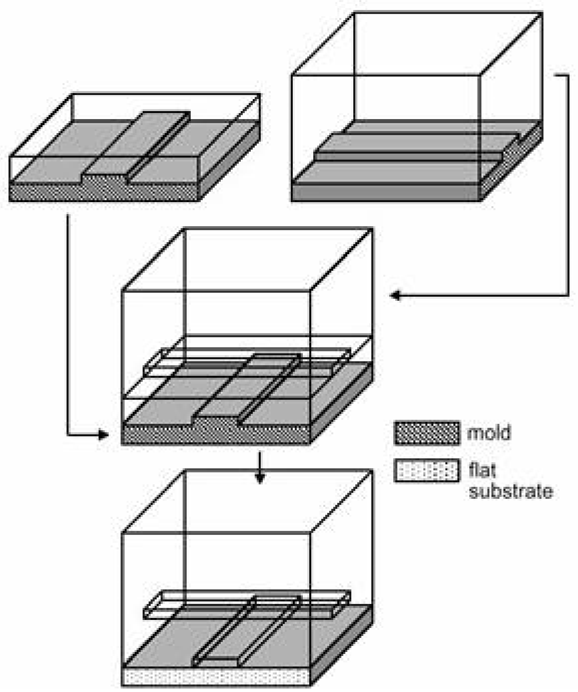
Thermopneumatically actuated diaphragm valve micropump

[van de Pol et al., Sensors & Actuators, 1990]

Lecture outline

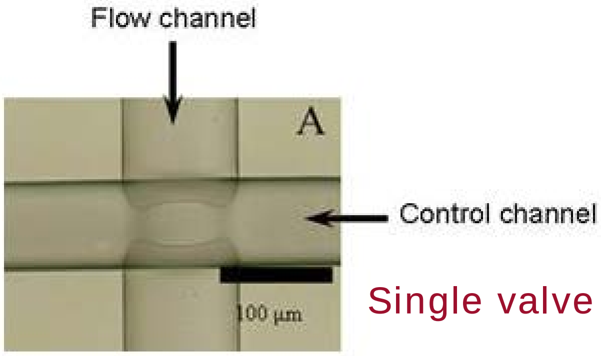
- Gas microvalves
- Inkjet printheads
- Micropumps
- Power-MEMS
  - Fuel cells
  - Microcombustion systems
- Examples of commercially available multifunctional microfluidic platforms
  - PDMS based fluidic microfluidic platforms
  - CD-based microfluidic platforms
  - EWOD based "digital microfluidic" platforms
  - Droplet-based platforms
- Microfluidic solutions for diagnostic devices
- Micro-macro fluidic interfaces
  - Nebulisers
  - ESI tips

PDMS based microfluidic microfluidic platform



Fabrication

⇨



Single valve

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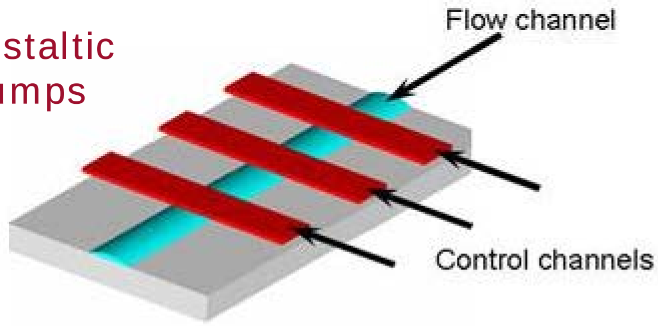
Peristaltic pumps



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System integration

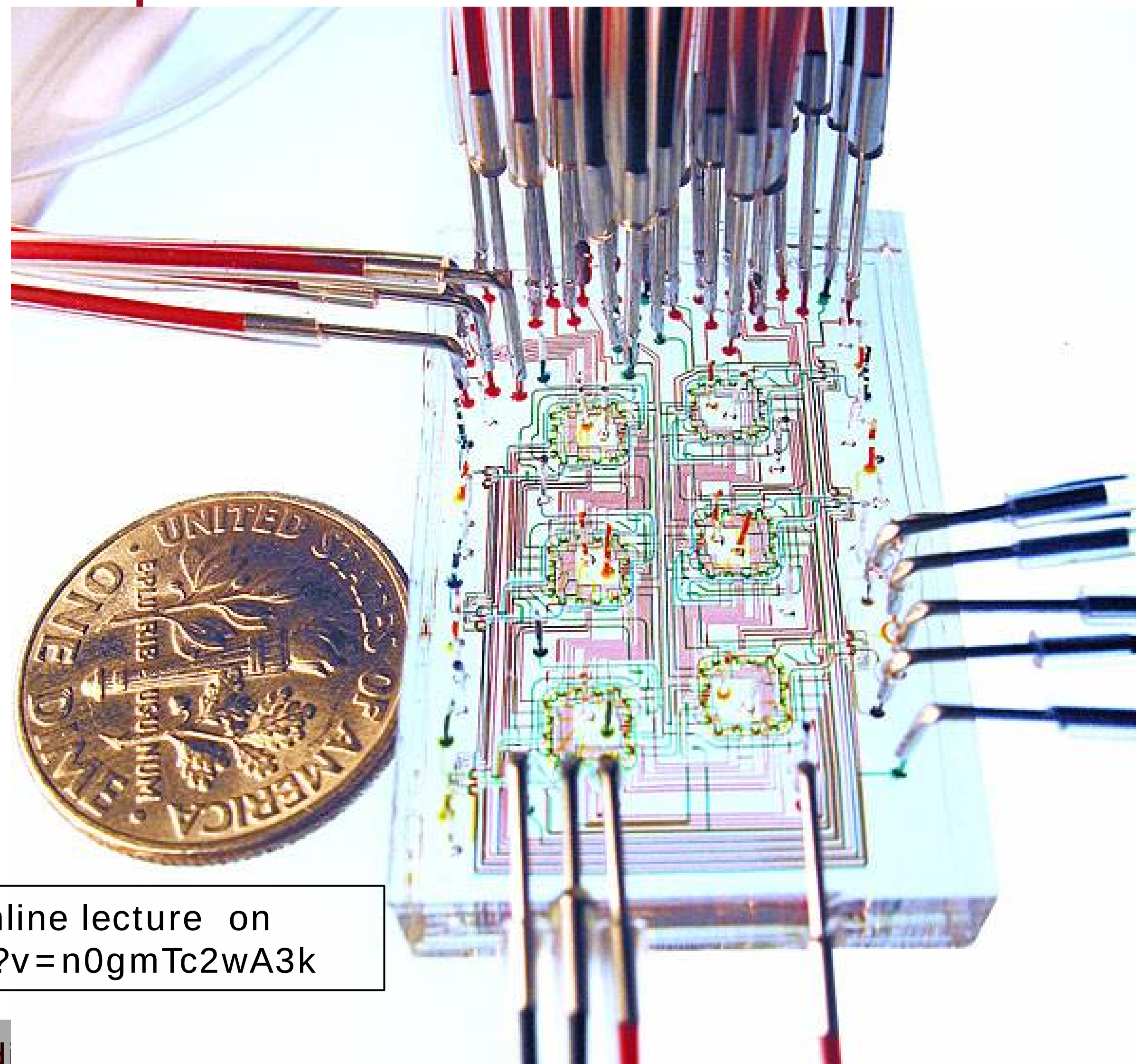
[S. Quake et al., Stanford University]

See also: www.fluidigm.com

PDMS based microfluidic microfluidic platform

Interfacing requirements:

- Input:
  - Sample
  - Reagents
- Output:
  - Reaction products
  - Waste
- Pneumatic control lines:
  - Integrated fluidic multiplexer:
  - 2n+1 control lines steer n^2 single valve units



More information: Stanford online lecture on http://www.youtube.com/watch?v=n0gmTc2wA3k

Lecture outline

- Gas microvalves
- Inkjet printheads
- Micropumps
- Power-MEMS
  - Fuel cells
  - Microcombustion systems
- Examples of commercially available multifunctional microfluidic platforms
  - PDMS based fluidic microfluidic platforms
  - CD-based microfluidic platforms
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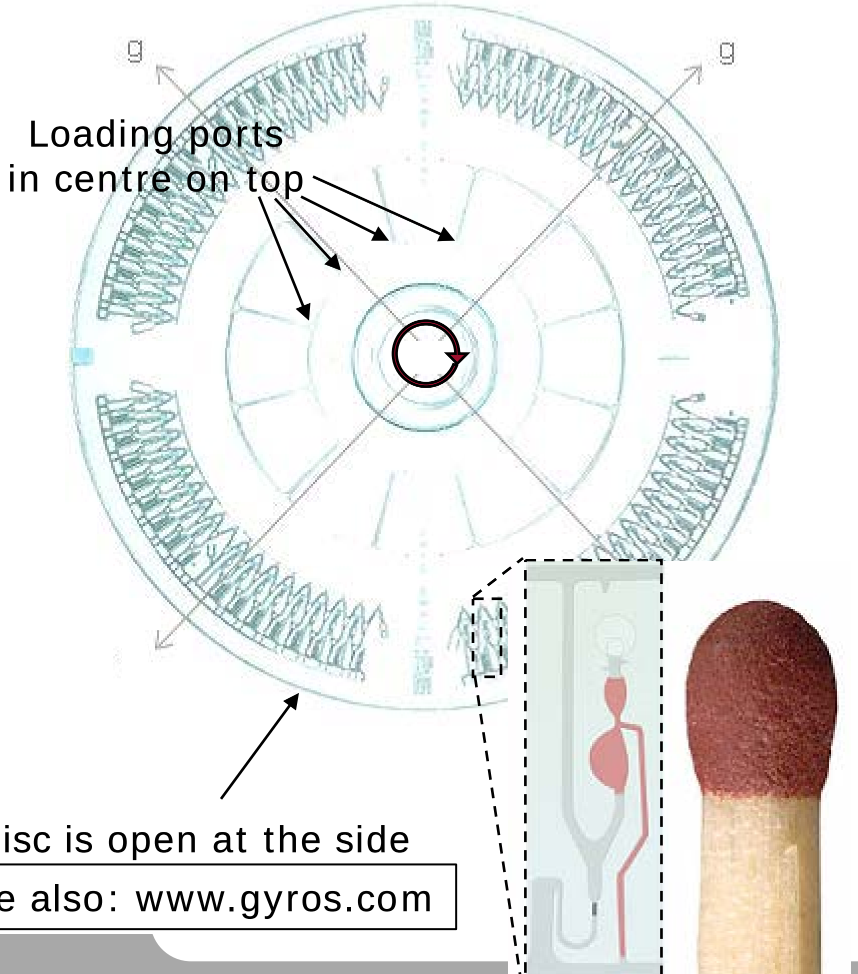
  - Droplet-based platforms
- Microfluidic solutions for diagnostic devices
- Micro-macro fluidic interfaces
  - Nebulisers
  - ESI tips

Lab-on-CD

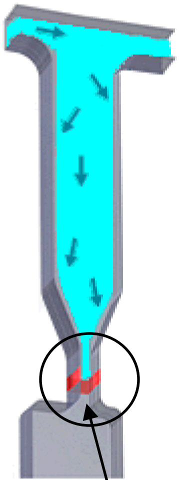


See also: www.gyros.com

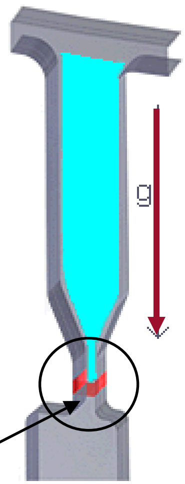
- Fabrication:
  - 2-layer plastic CD
  - molded microfluidic channels
- Liquid manipulation forces
  - Capillary force
  - Spinning
  - Coriolis forces
- Integrated fluidic functionality:
  - Valving, Dosing, Pumping, Mixing
- Applications:
  - MALDI preparation
  - Cell incubation
  - …

[Photographs: Gyros Microlabs, Upsala]

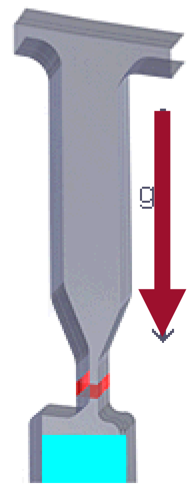
Dosing in a rotational fluidic microfluidic platform



Capillary force draws liquids into a distribution channel, filling a volume definition chamber.



As the CD spins, the distribution channel empties, leaving behind a precisely defined liquid volume.

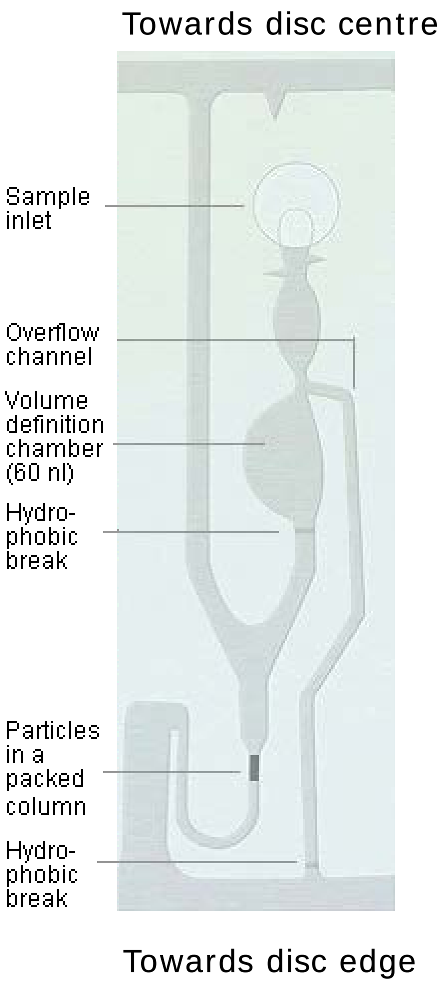


A second spin, at higher speed, creates a g-force sufficient to drive the liquid over the hydrophobic break.

A hydrophobic break (in red) prevents liquid moving further into the microstructure.

[illustrations: Gyros Microlabs, Upsala]

Gyros Lab-CD technology

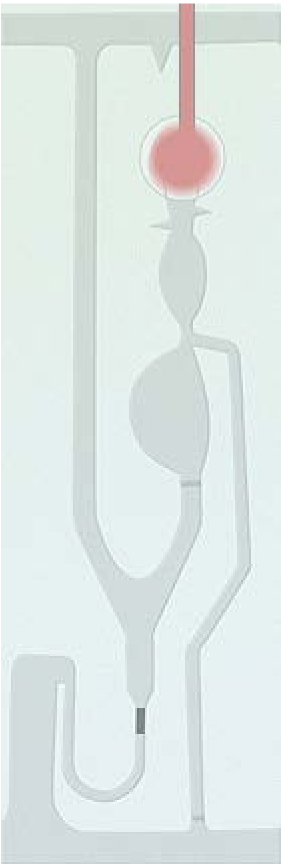


1. Liquid drawn in by capillary action.

2. Overflow channel activated at a low spin speed, removing excess liquid.

3. Volume (60 nl) defined within the chamber.

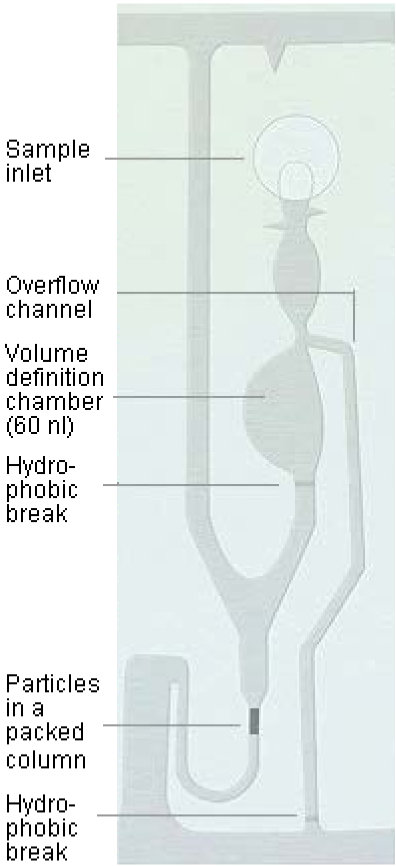
4. Defined volume moves through packed column by increasing spin speed.



[www.gyros.se]

Gyros Lab-CD technology

Towards disc centre



Towards disc edge

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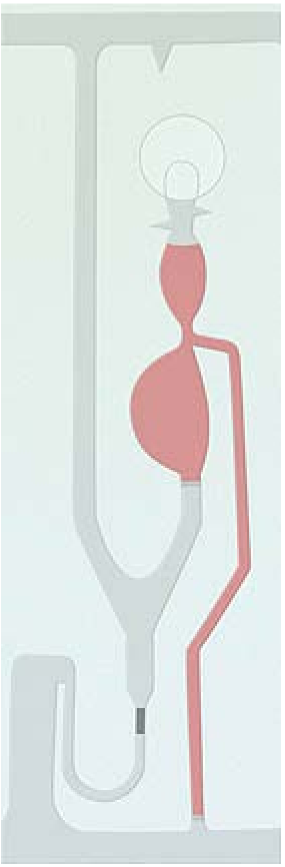
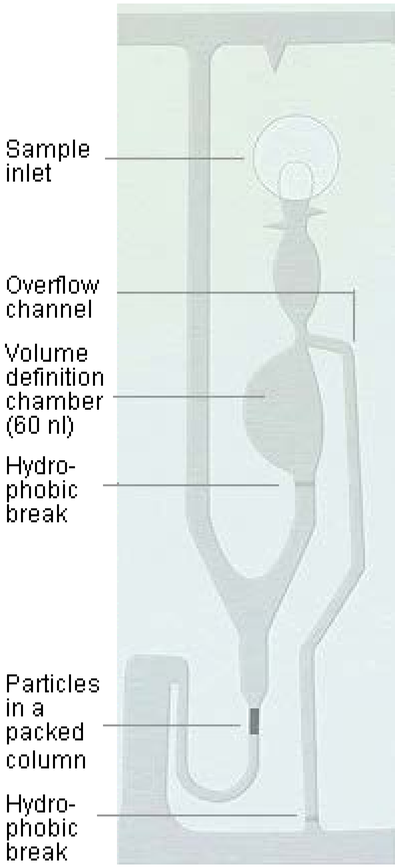


[www.gyros.se]

Gyros Lab-CD technology

Towards disc centre



Towards disc edge

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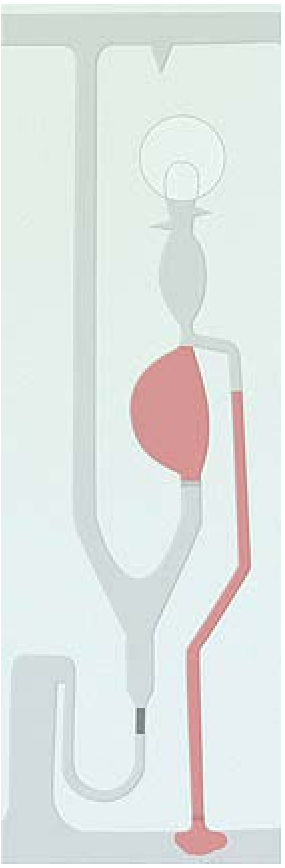
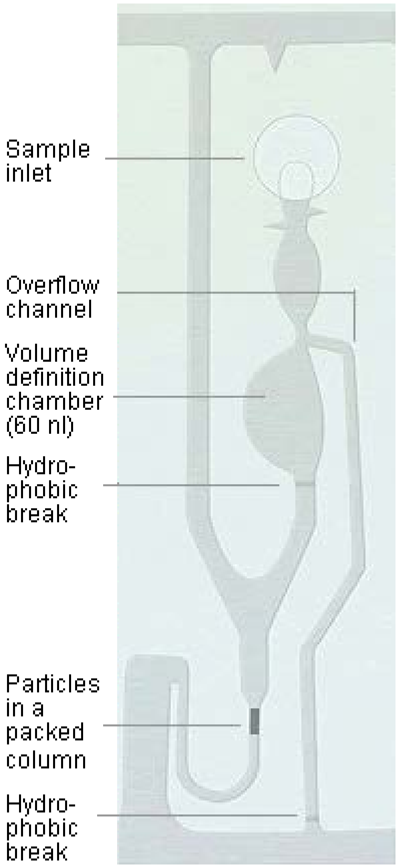


[www.gyros.se]

Gyros Lab-CD technology

Towards disc centre



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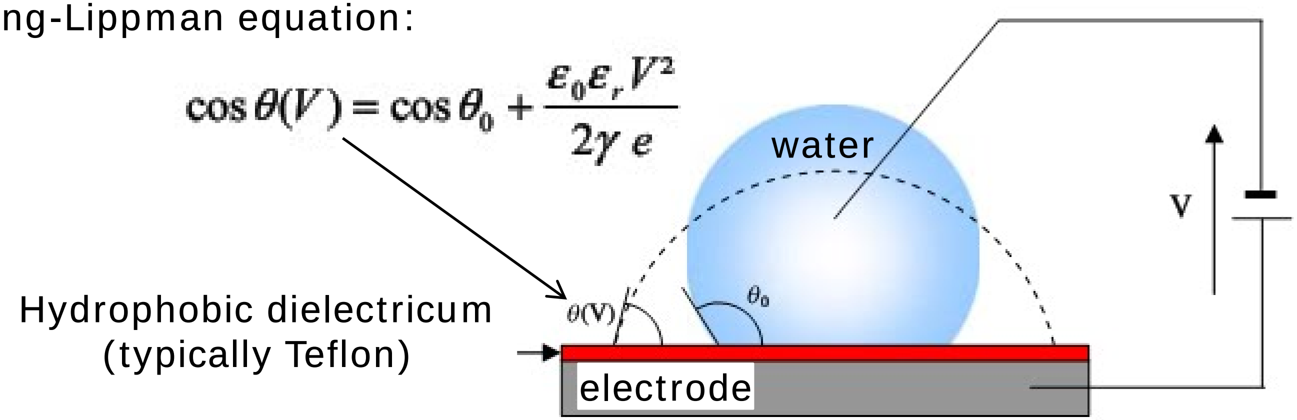
EWOD: ElectroWetting On Dielectric

Young-Lippman equation:

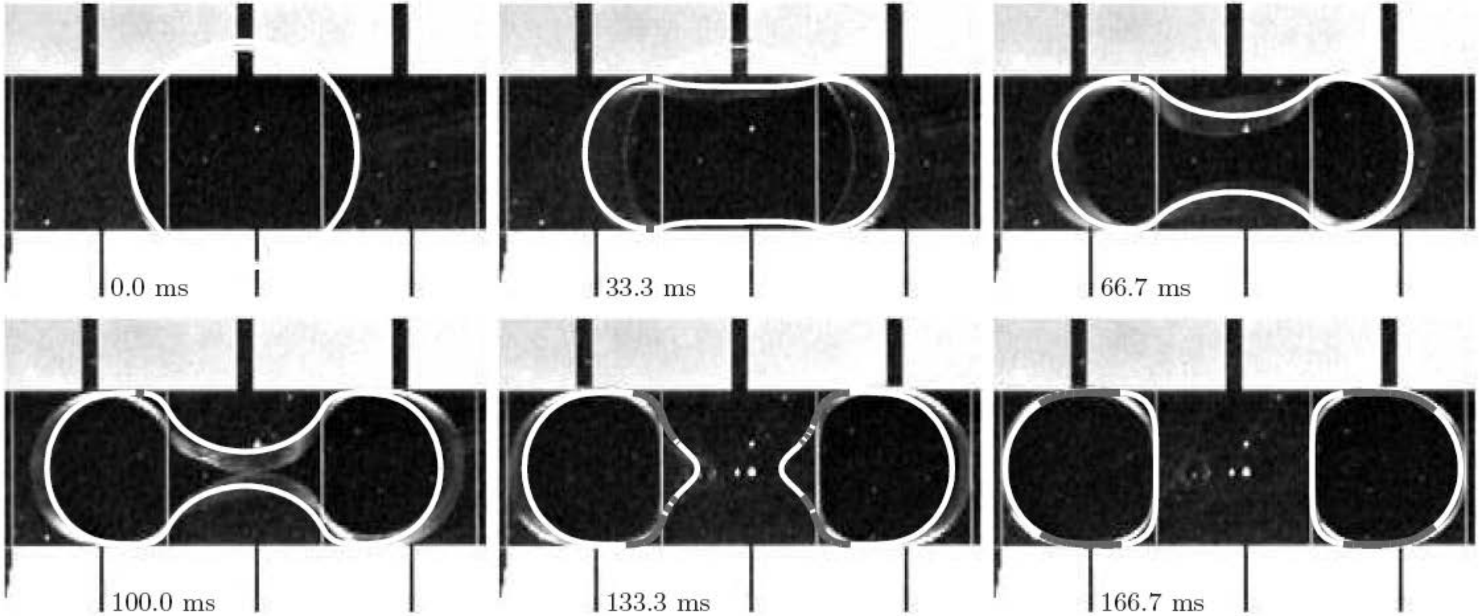
$$\cos\theta(V) = \cos\theta_0 + \frac{\varepsilon_0 \varepsilon_r V^2}{2\gamma\, e}$$



- The water and solid electrode form the electrodes of a capacitor.
- When charging the capacitor, the capacitor will try to minimise its energy by bringing charges close to eachother.
- It does this by spreading the water on the surface

EWOD as transport mechanism

U=V U=0 U=V [CJ Kim, UCLA]



- When a droplet is in contact with several electrodes, it will move to the region with lowest contact angle.
- This can be used to move, split and merge droplets.

VIDEO: http://www.youtube.com/watch?v=_OJ_lorXUg4&NR=1

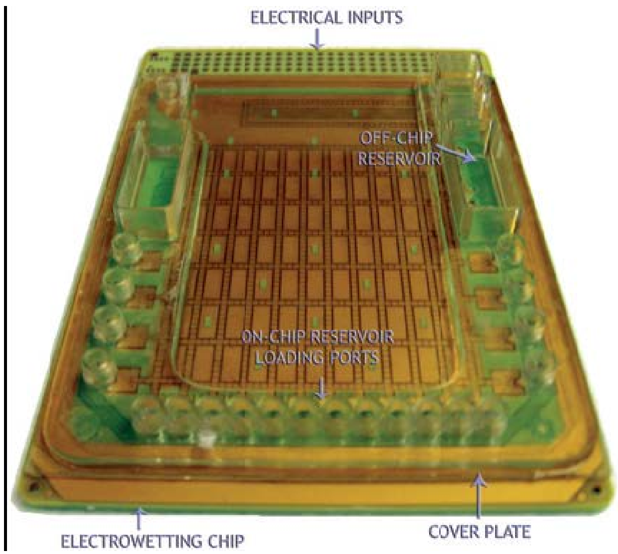
Some examples of EWOD platforms:

- Digital microfluidic DNA analysis

  http://www.youtube.com/watch?v=JvDZh8hmR84&feature=related

- Digital microfluidics for point-of-care testing

Duke Uni Digital Microfluidics.mp4



[Advanced Liquid Logic Inc]

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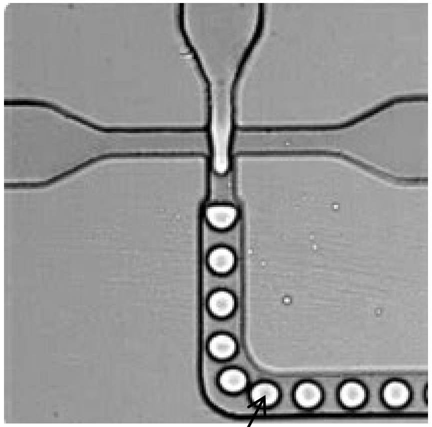
Droplet based microfluidics

Water-based bioreagents

Fluorinated oil



Fluorinated oil

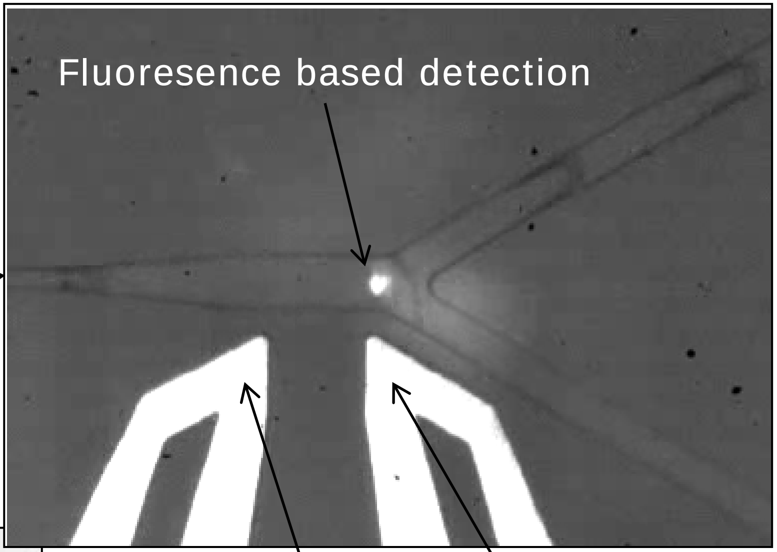
~3000 droplets/second
Every droplet = 1 bioreactor

⇨ High-throughput screening!

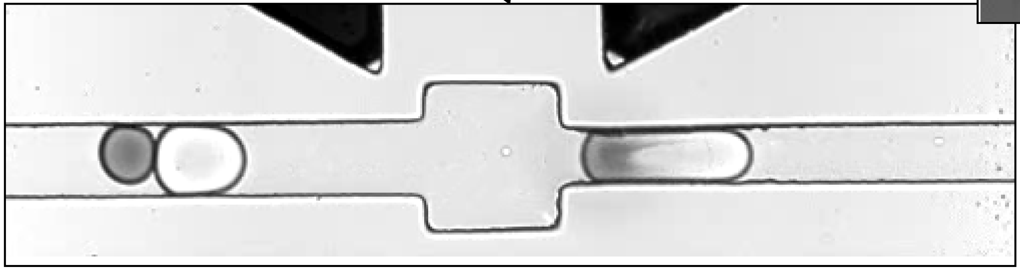
[www.raindancetechnologies.com]

Droplet based microfluidics

- Basic microfluidic operations:
  - Droplet generation
  - Droplet storage
  - Droplet sorting
  - Droplet merging



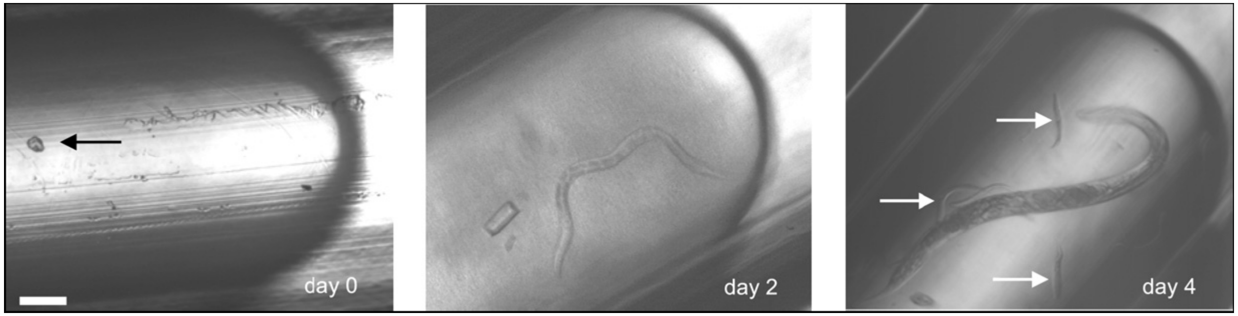
Electrodes for dielectrophoretic sorting



Video: http://raindancetechnologies.com/technology/pcr-genomics-research.asp

Some examples of the use opf droplet based microfluidics

- Major application: high throughput drug screening
- Screening for directed protein evolution [Agresti et al., PNAS, vol 107, no 9, 2010, 4004-4009]
- Culture mamalian cells and entire animals (C. Elegans) on chip. [Clausell-Tormos et al., Chemistry & Biology 15, 427–437, 2008]



C. Elegans: egg worm larvae

Lecture outline

- Classification of microfluidic components and systems
- Gas microvalves
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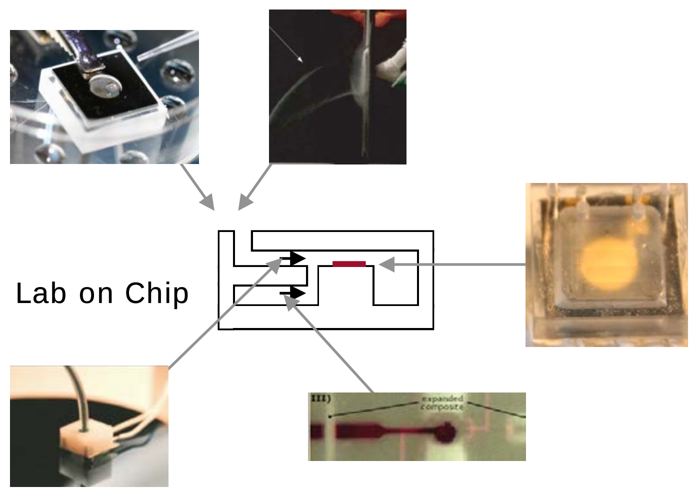
Microfluidic solutions for label-free diagnostic sensors



Wouter van der Wijngaart

Microsystem Technology Lab,
KTH – the Royal Institute of Technology,
Stockholm, SWEDEN

Collaborators:

- Work on narcotics detection platform:
  - Thomas Frisk, Wouter van der Wijngaart, Göran Stemme (KTH – the Royal Institute of Technology)
  - David Rönnholm, Per Månsson, Lars Eng (Biosensor Applications, Stockholm, Sweden)

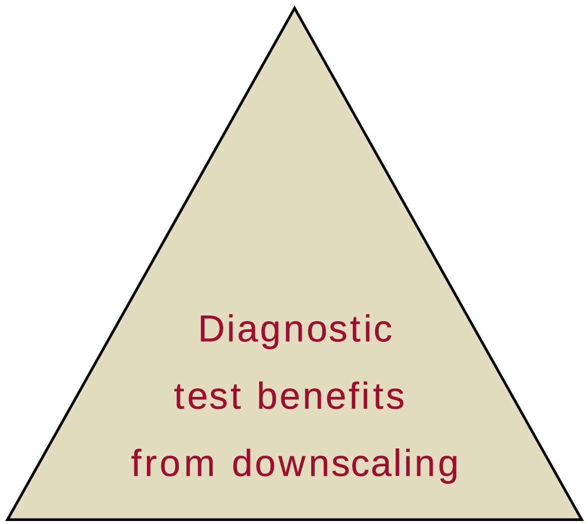
- Work on virus detection platform:
  - Niklas Sandström, Thomas Frisk, Göran Stemme Wouter van der Wijngaart, (KTH – the Royal Institute of Technology)
  - Hans Wigzell (Karolinska Institutet)
  - Lennart Svensson (Linköping University)

- Work on integrated microfluidic actuators platform:
  - Björn Samel, Niklas Roxhed, Patrick Griss, Göran Stemme (KTH – the Royal Institute of Technology)

Potential drivers for miniaturization in IVD

Application demands small size

- Small amount of sample
- Portability
- Limited space at POC



Increased performance

- Novel functionality
- Faster system
- Low sample dispersion
- Sensor sensitivity

Decreased cost

- Manufacturing cost
- Materials cost
- Consumables reduction
- Enabling disposables

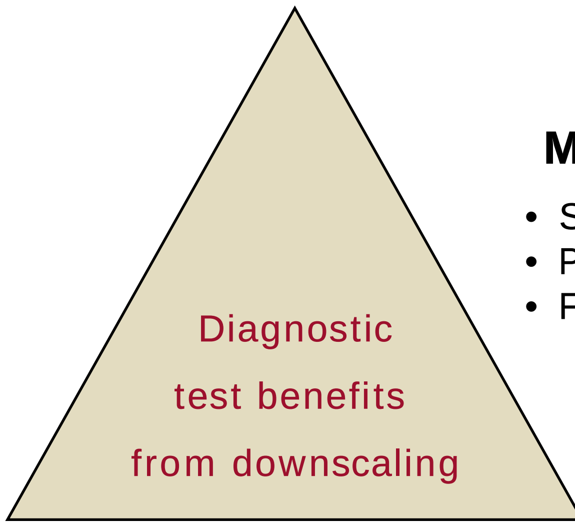
Miniaturization enablers

Application demands small size

- Small amount of sample
- Portability
- Limited space at POC

Phys. laws of scaling

- Low inertia: fast response
- Short distance:
    - Fast transport
    - Diffusive transport
- Large surface/volume ratio:
    - Surface tension
    - Surface interactions
    - Laminar flow
    - ...



Microsystem manufacturing

- Semiconductor manufacturing
- Polymer microreplication
- Functional integration

Increased performance

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Decreased cost

- Manufacturing cost
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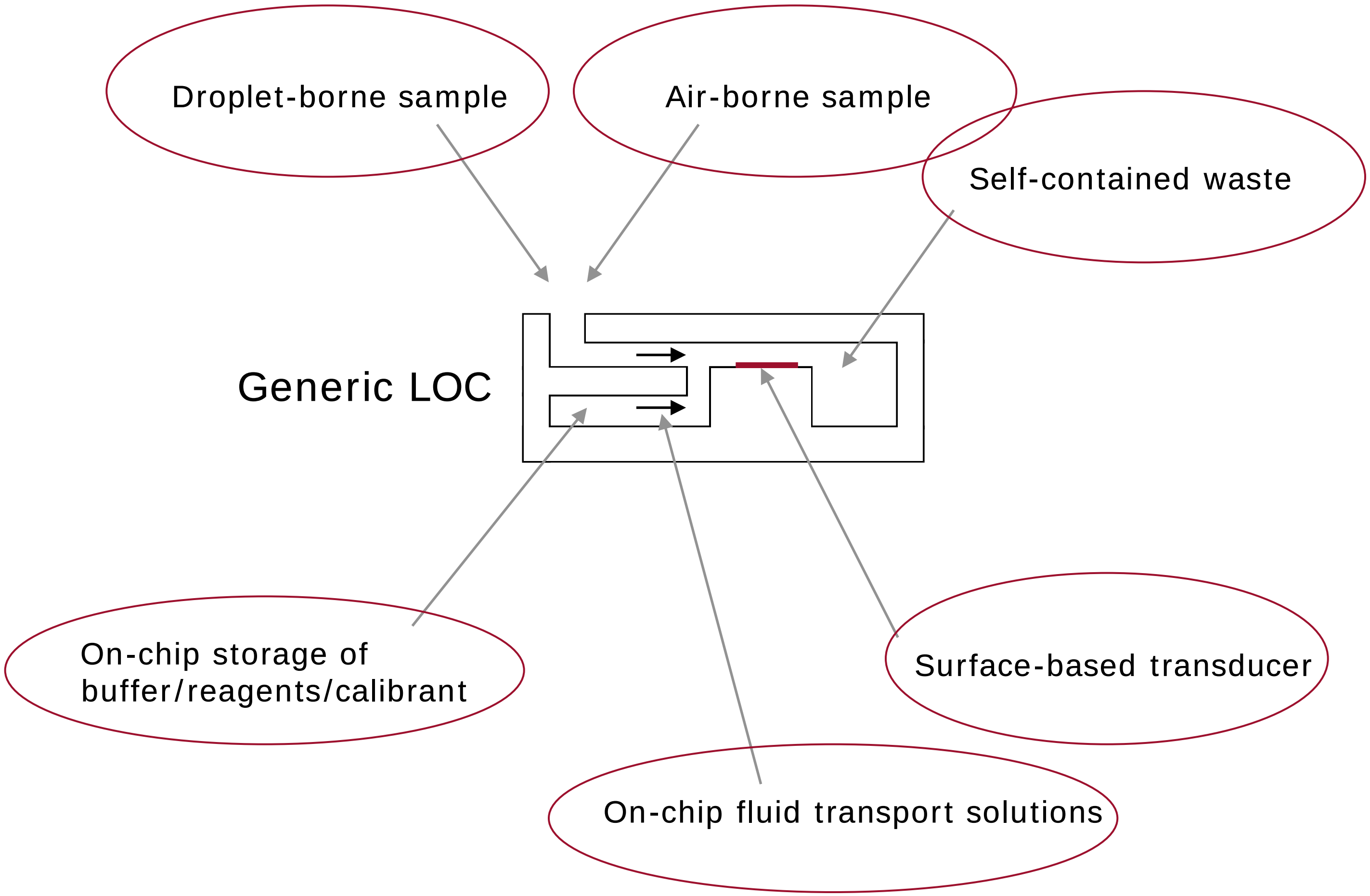
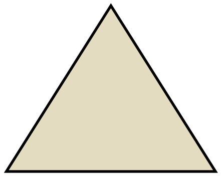
Generic microfluidic solutions for improved analyte transport



Example: Miniaturisation of a narcotics detection instrument

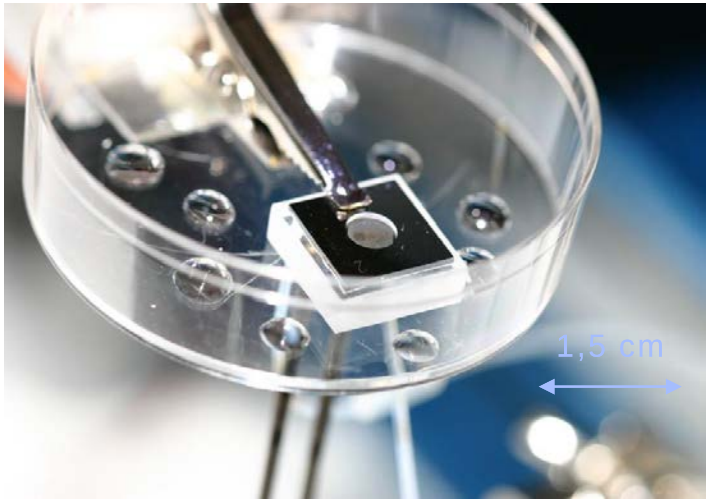
[www.biosensor.se]

Size:
50.000 x smaller



Functionality:
5 x faster

Cost:
Less material
Less assembly
100 x less consumables



Example: mass transport in a narcotics detection instrument

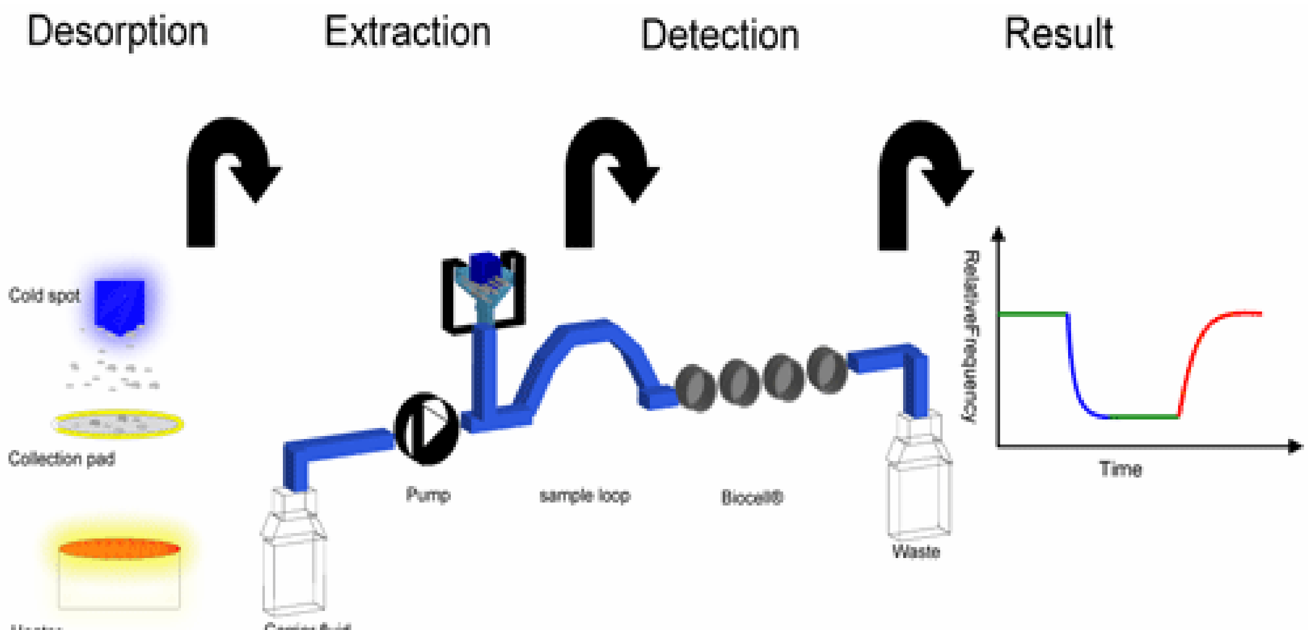
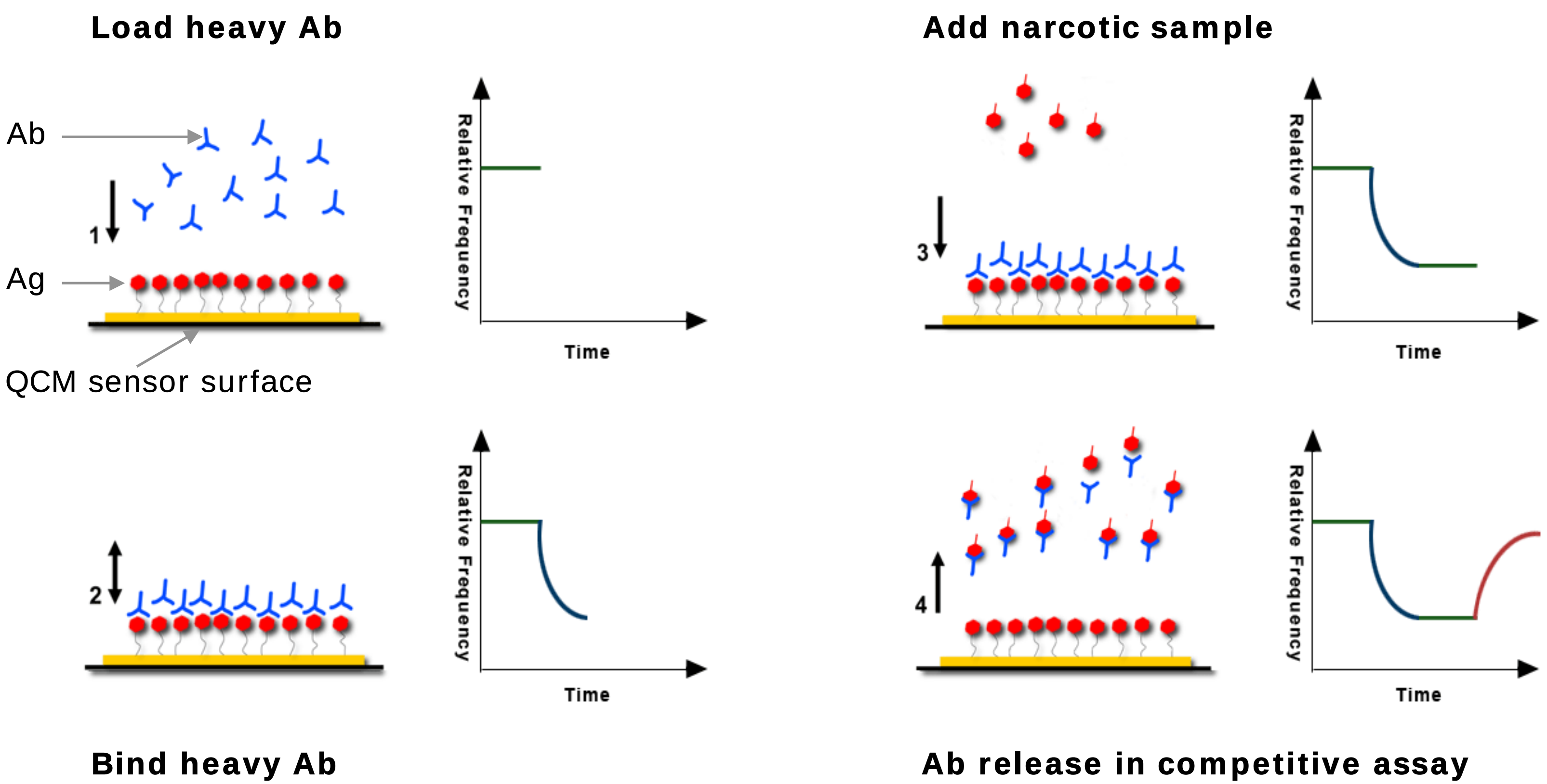


FIGURE 3

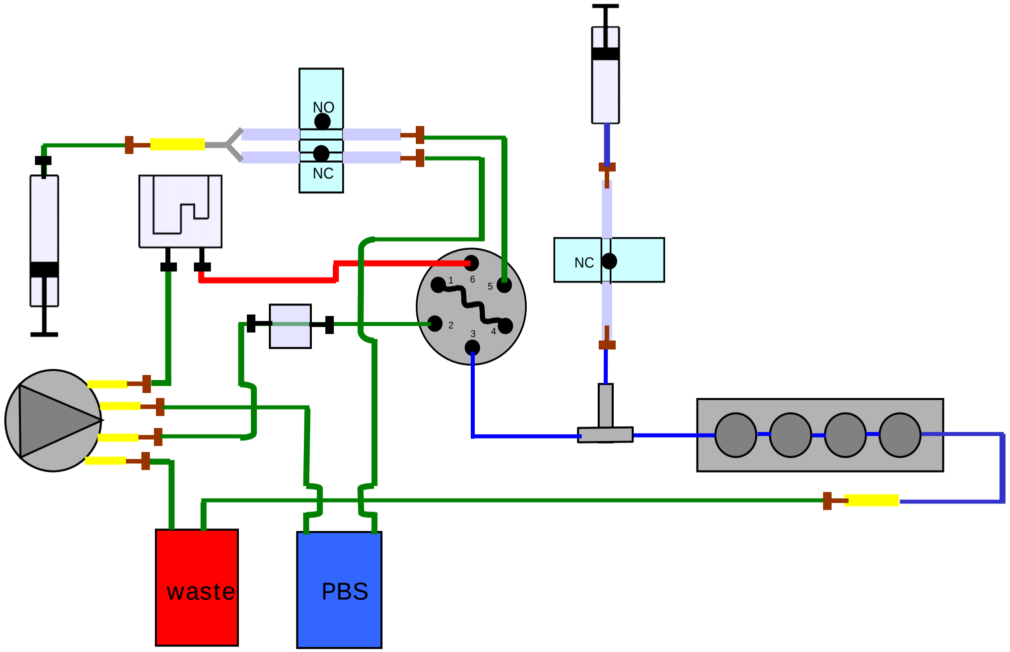
[www.biosensor.se]

Example: narcotics detection immunoassay



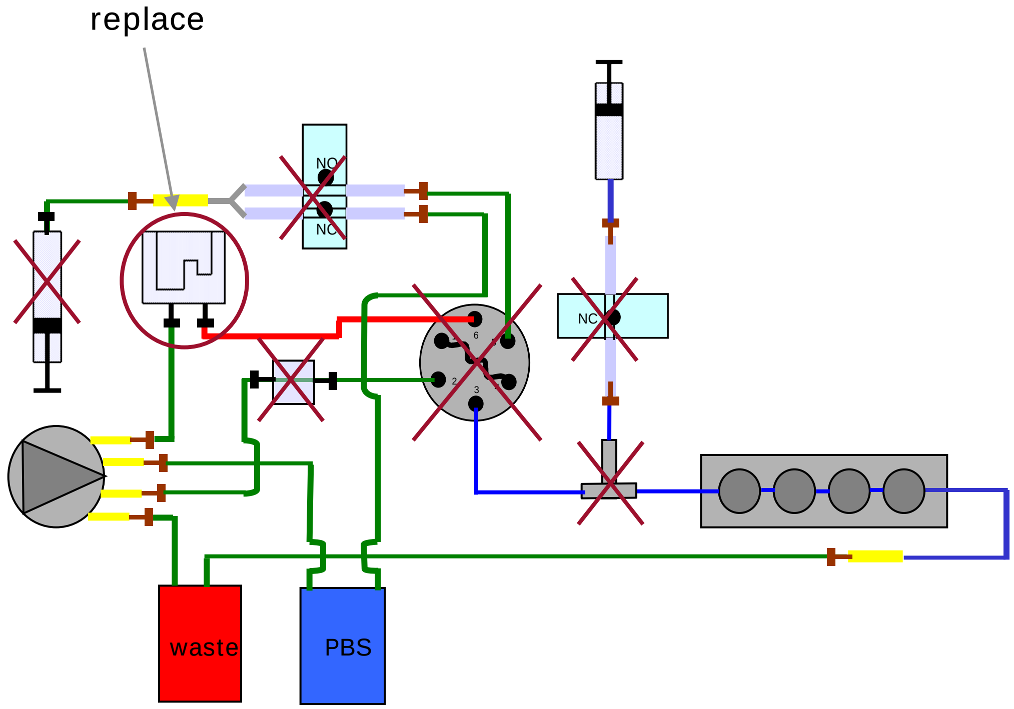
[www.biosensor.se]

Example: Miniaturisation of a narcotics detection instrument



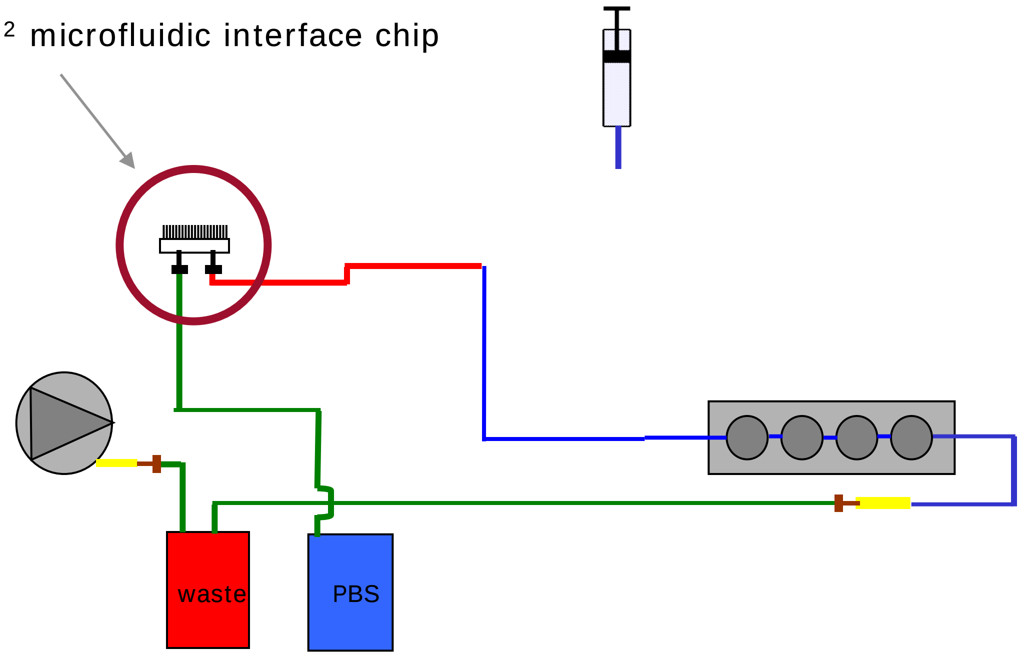
Phase 1 of miniaturisation

- Reduce tubing → Reduce sample transport time
- Reduce tubing → reduce dispersion
- Reduce costs of valves and pumps



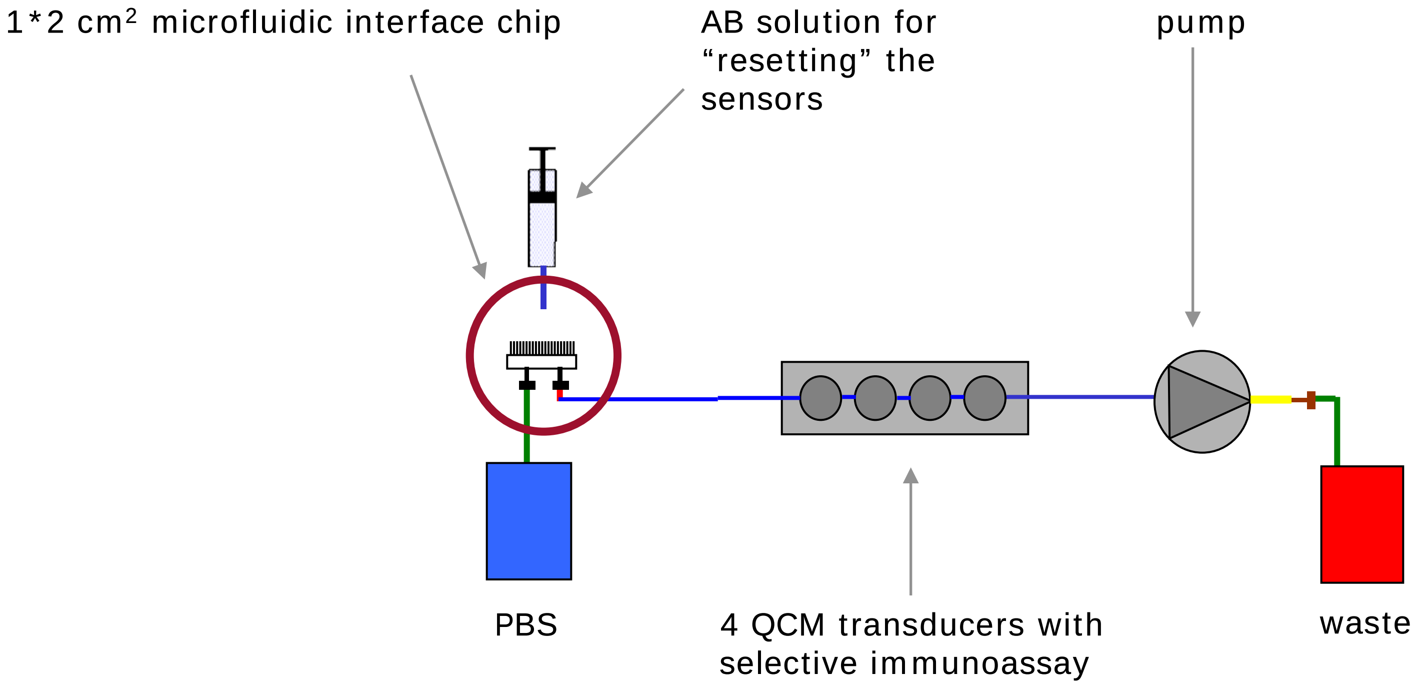
Phase 1 of miniaturisation

1*2 cm^2 microfluidic interface chip

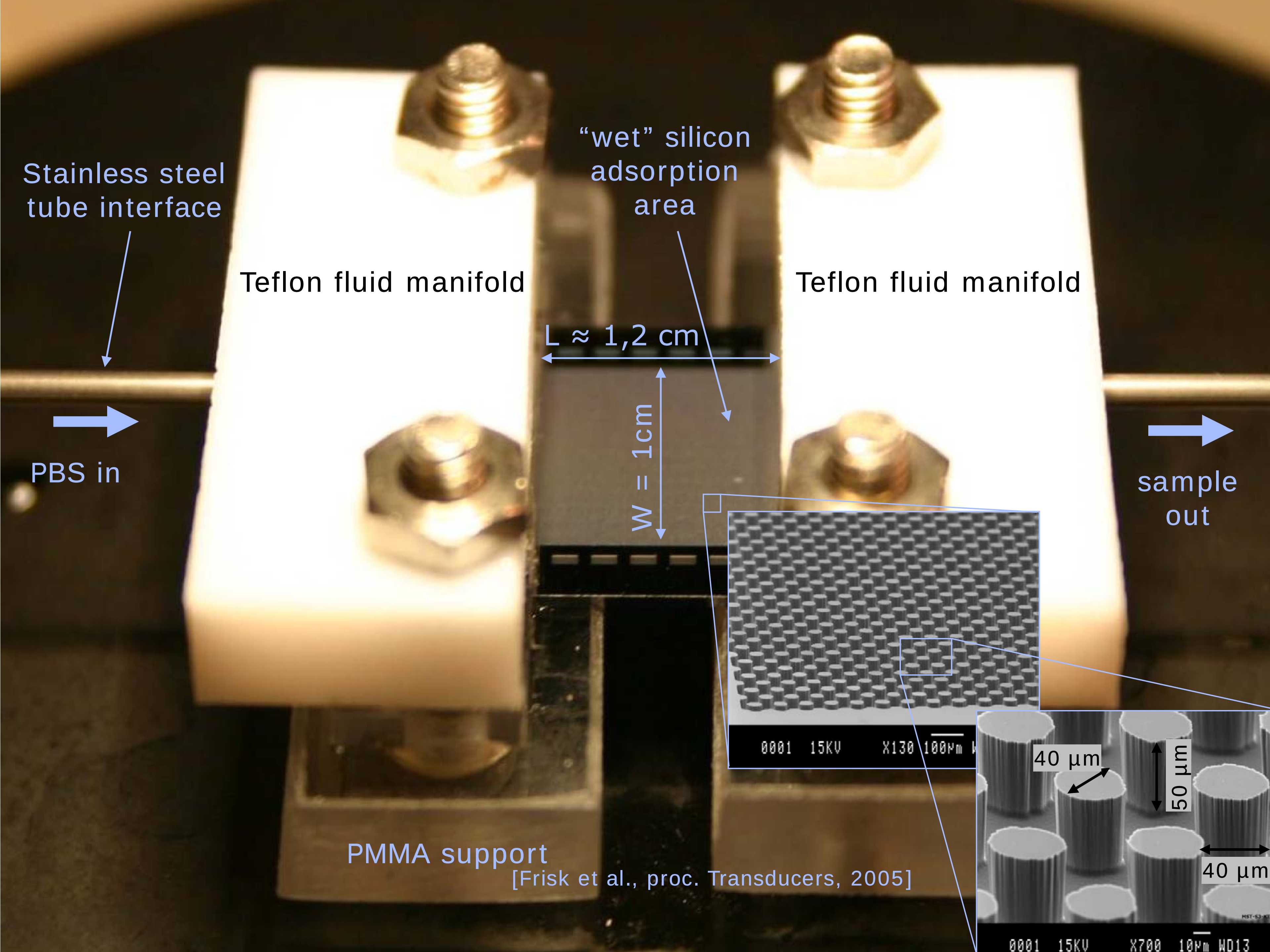


[Frisk et al., Lab Chip 6, 2006]

Phase 1 of miniaturisation



[Frisk et al., Lab Chip 6, 2006]

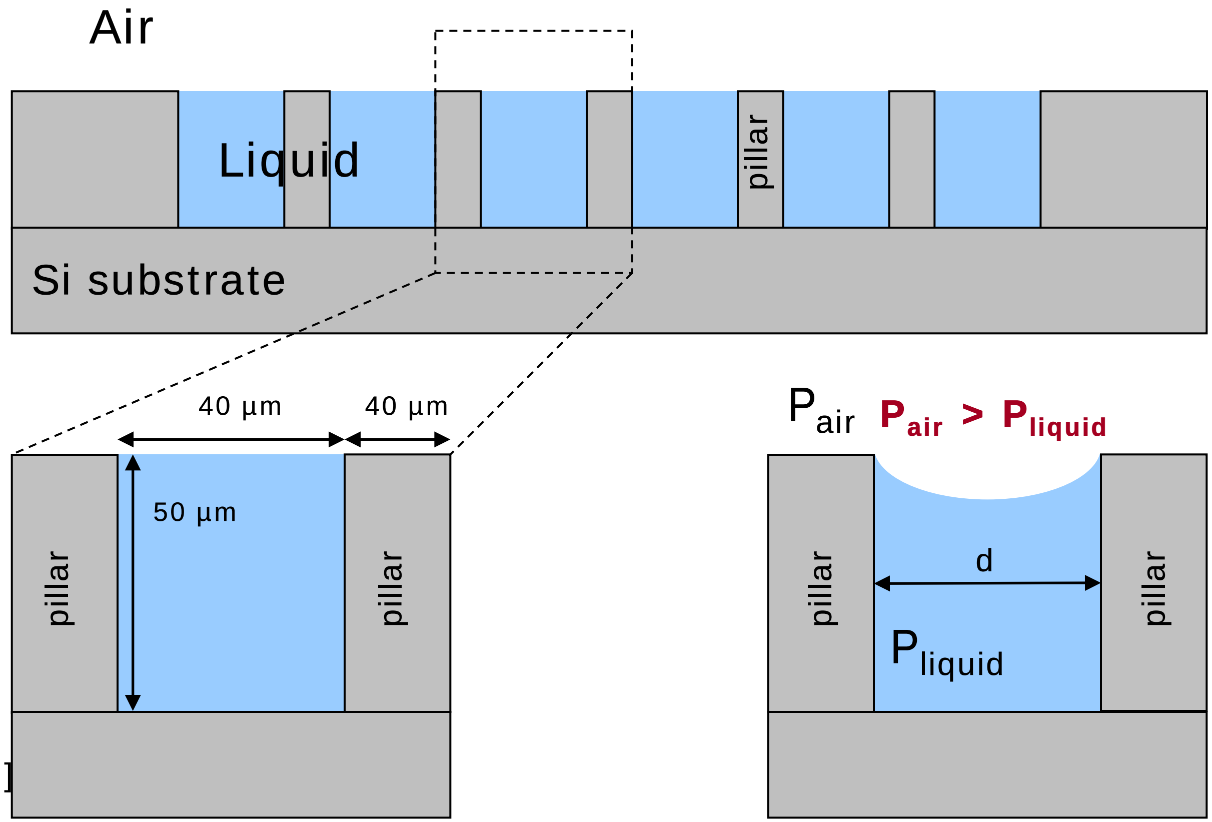


[Frisk et al., proc. Transducers, 2005]

Microstructured interface design

$$P_{air} - P_{liquid} \propto \frac{\gamma}{d}$$

Surface tension provides a robust interface



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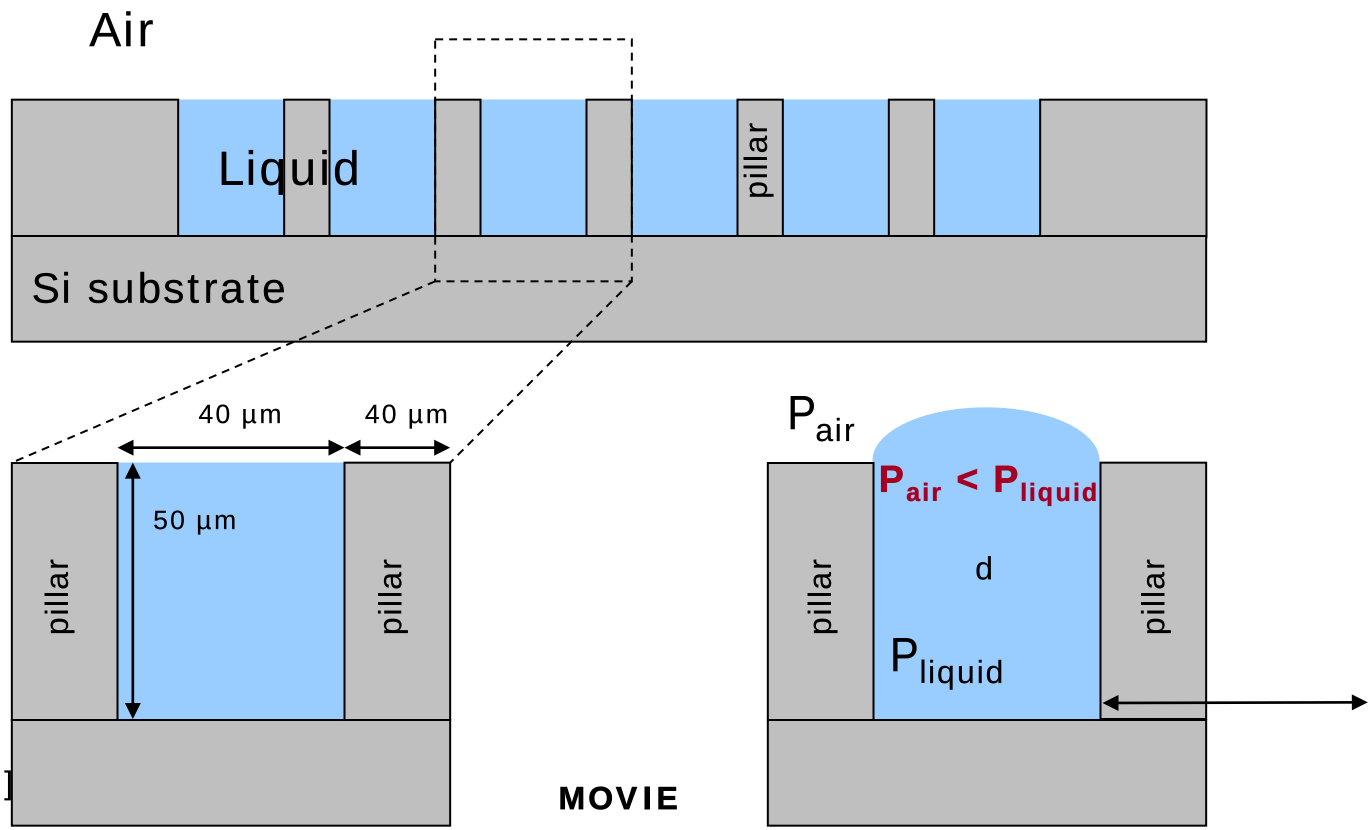
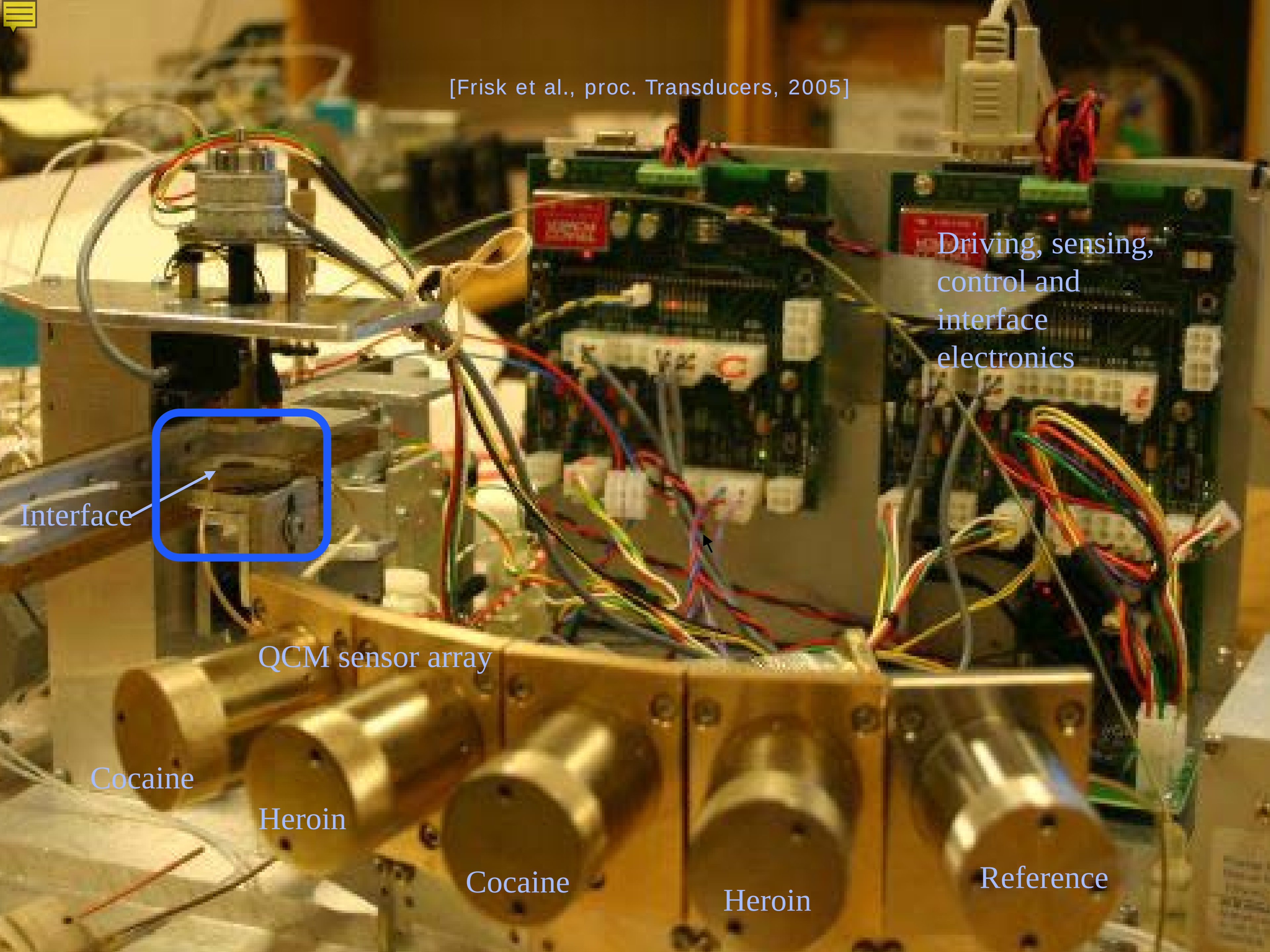
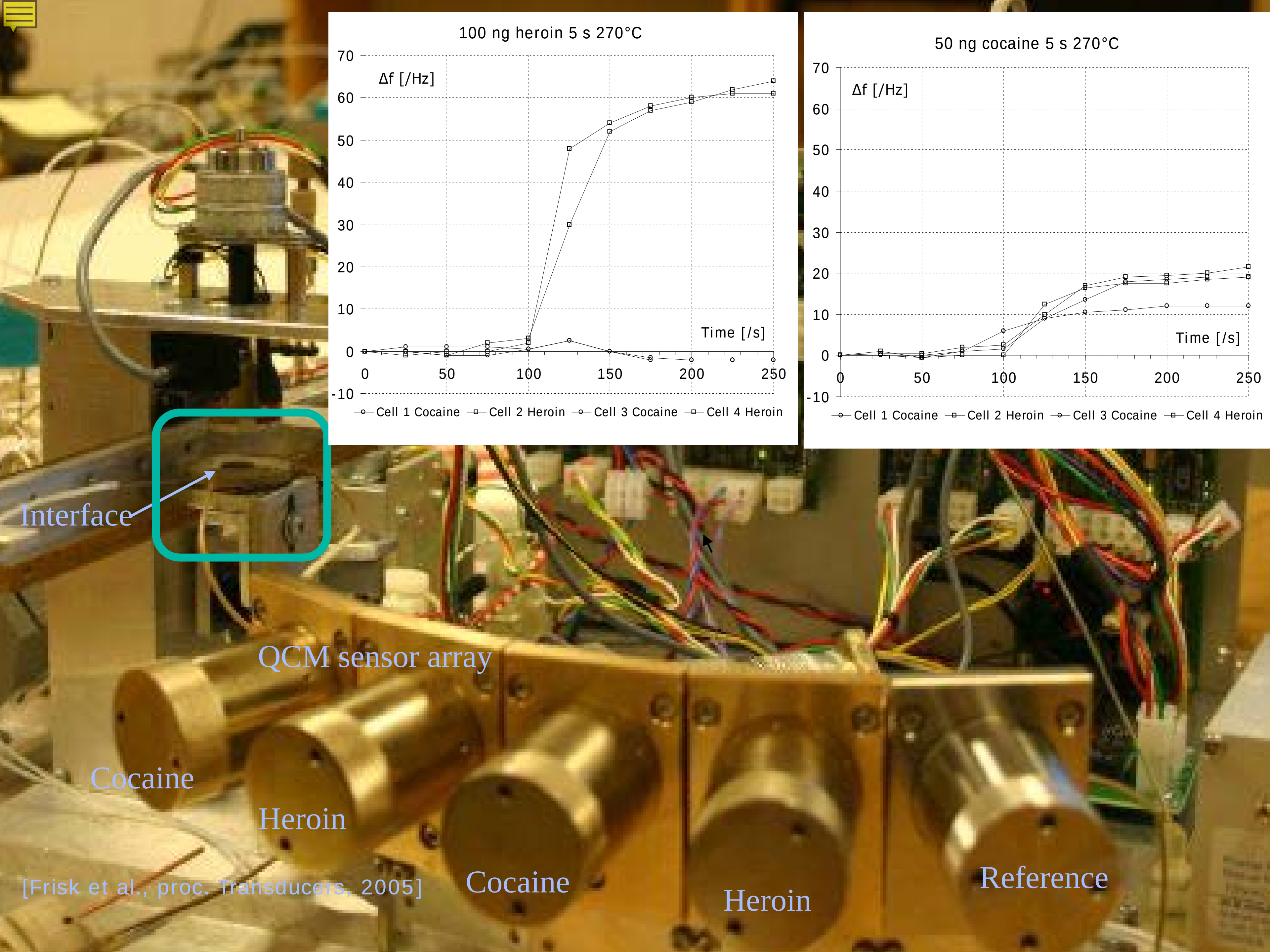


[Frisk et al., Lab Chip 6, 2006]

MOVIE


[Frisk et al., proc. Transducers, 2005]
Driving, sensing, control and interface electronics
Interface
QCM sensor array
Cocaine
Heroin
Cocaine
Heroin
Reference


100 ng heroin 5 s 270°C
Δf [/Hz]
Time [/s]
Cell 1 Cocaine
Cell 2 Heroin
Cell 3 Cocaine
Cell 4 Heroin
50 ng cocaine 5 s 270°C
Δf [/Hz]
Time [/s]
Cell 1 Cocaine
Cell 2 Heroin
Cell 3 Cocaine
Cell 4 Heroin
Interface
QCM sensor array
Cocaine
Heroin
Cocaine
Heroin
Reference
[Frisk et al., proc. Transducers, 2005]

Phase 1 enablers

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Phys. laws of scaling

- Low inertia: fast response
- Short distance:
  - Fast transport
  - Diffusive transport
- Large surface/volume ratio:
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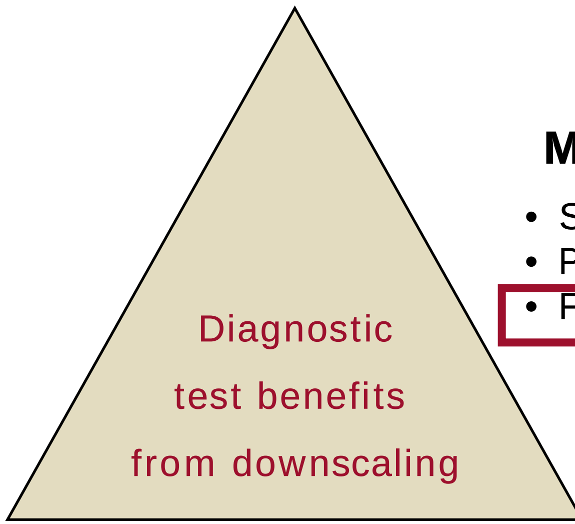
  - Surface interactions
  - Laminar flow
  - ...



Microsystem manufacturing

- Semiconductor manufacturing
- Polymer microreplication
- Functional integration

Increased performance

- Novel functionality
- Faster system
- Low sample dispersion
- Sensor sensitivity

Decreased cost

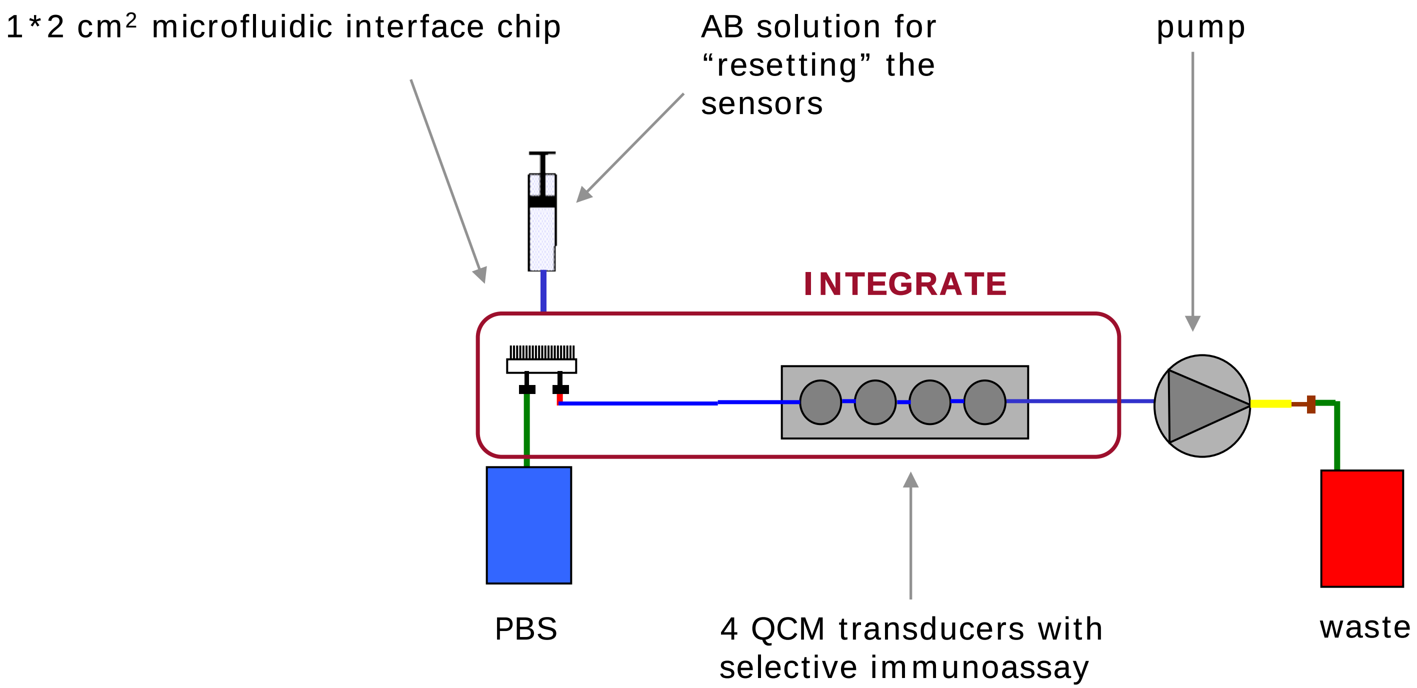
- Manufacturing cost
- Materials cost
- Consumables reduction
- Enabling disposables

Part 1 Device improvements

- Sample introduction without introducing air bubbles
- Transport time interface → transducer: 60s →30s
- Sample dispersion during transport strongly reduced
- System cost is strongly reduced

[Frisk et al., proc. IEEE MEMS, 2007]

Phase 2 of miniaturisation

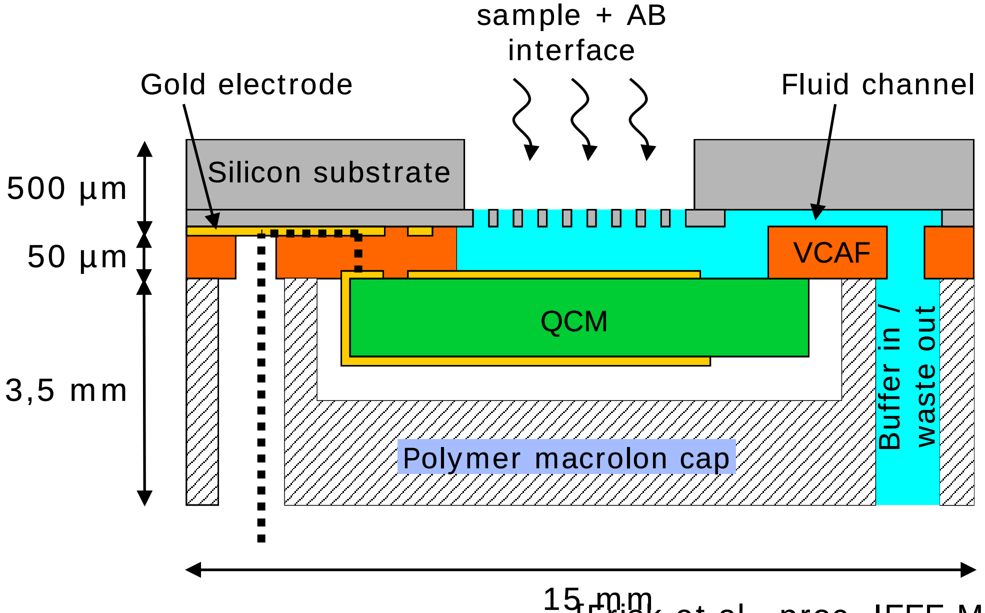


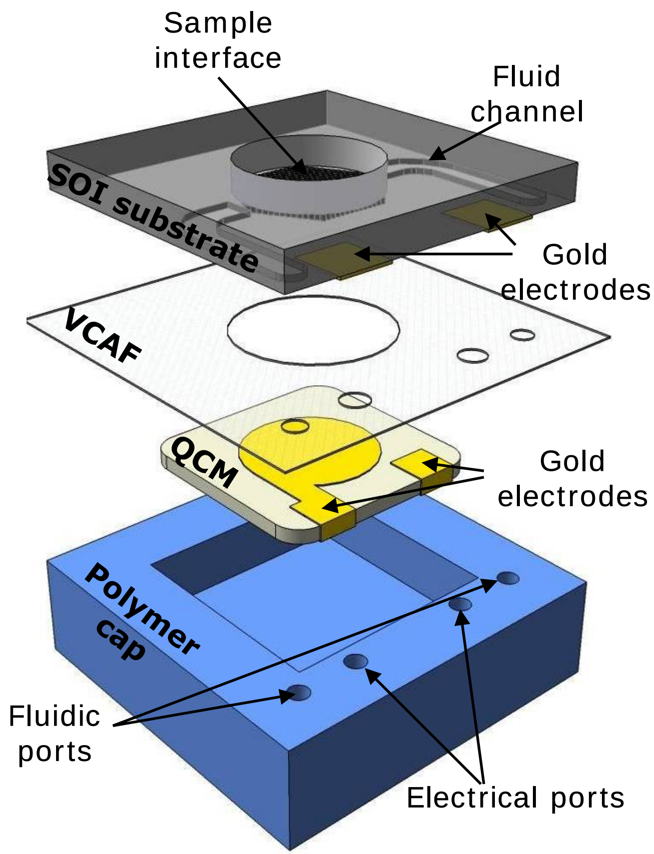
[Frisk et al., proc. IEEE MEMS, 2007]

Phase 2 of miniaturisation

Put the interface on top of the QCM

Cross-sectional view

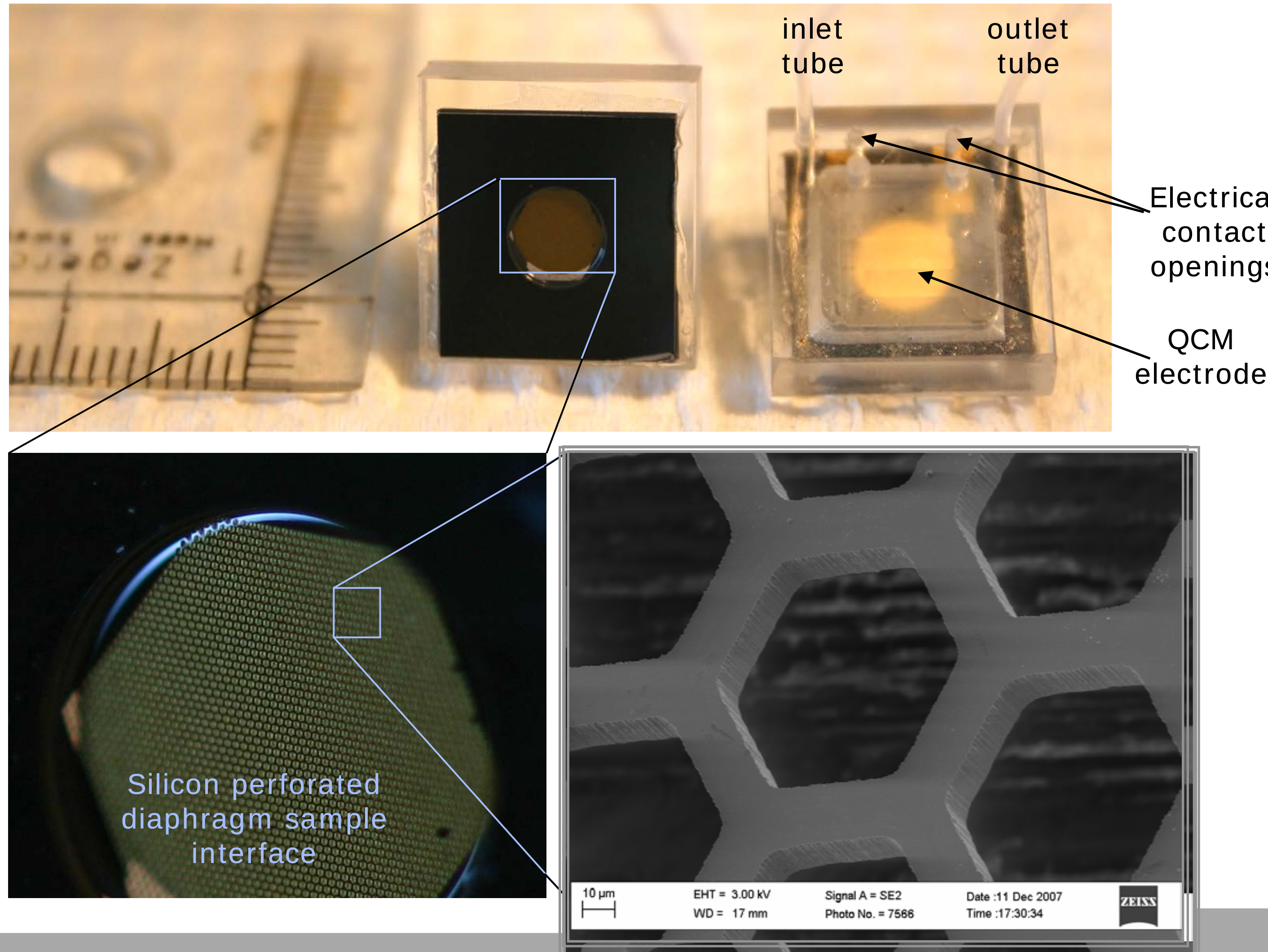




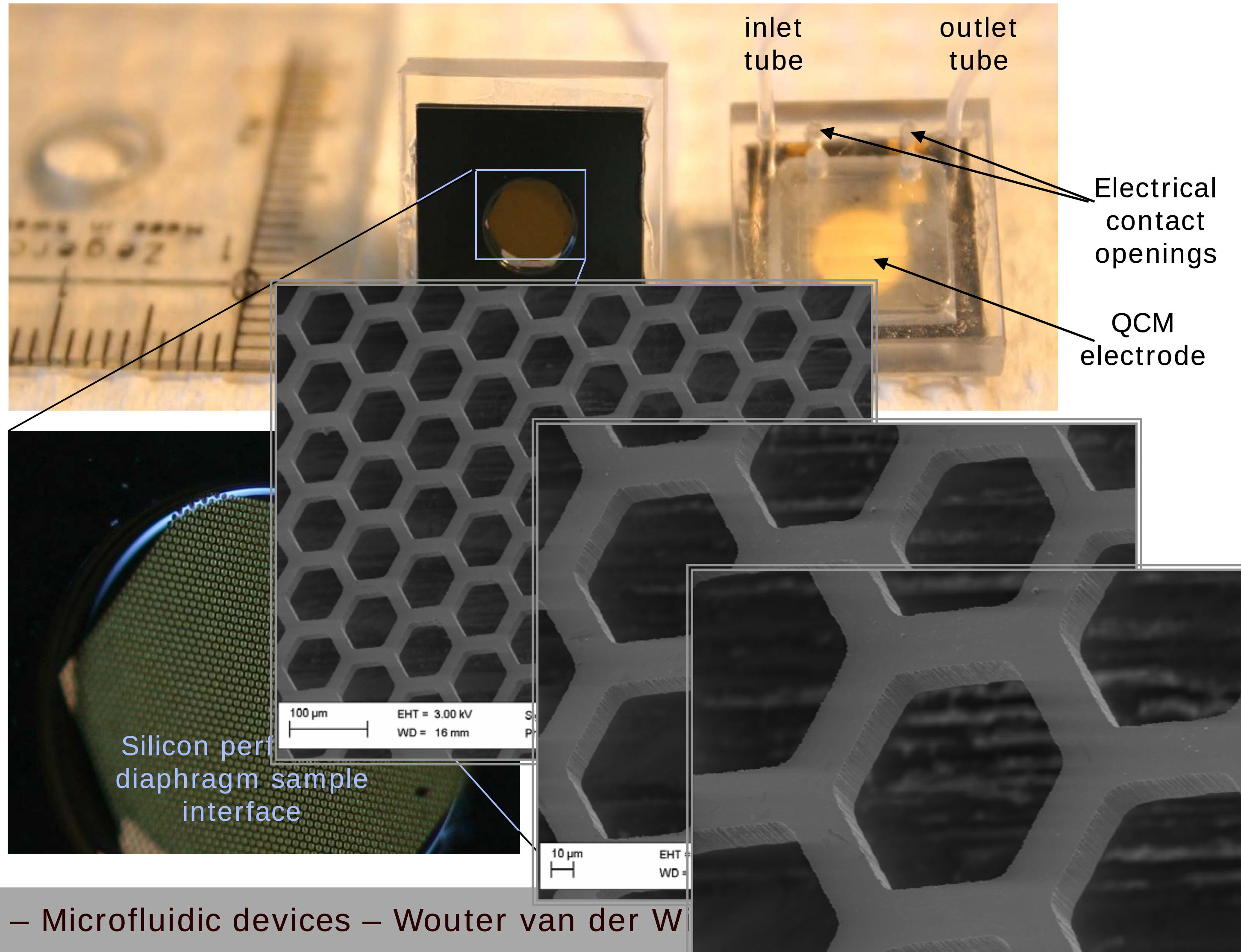
Exploded view

[Frisk et al., proc. IEEE MEMS, 2007]

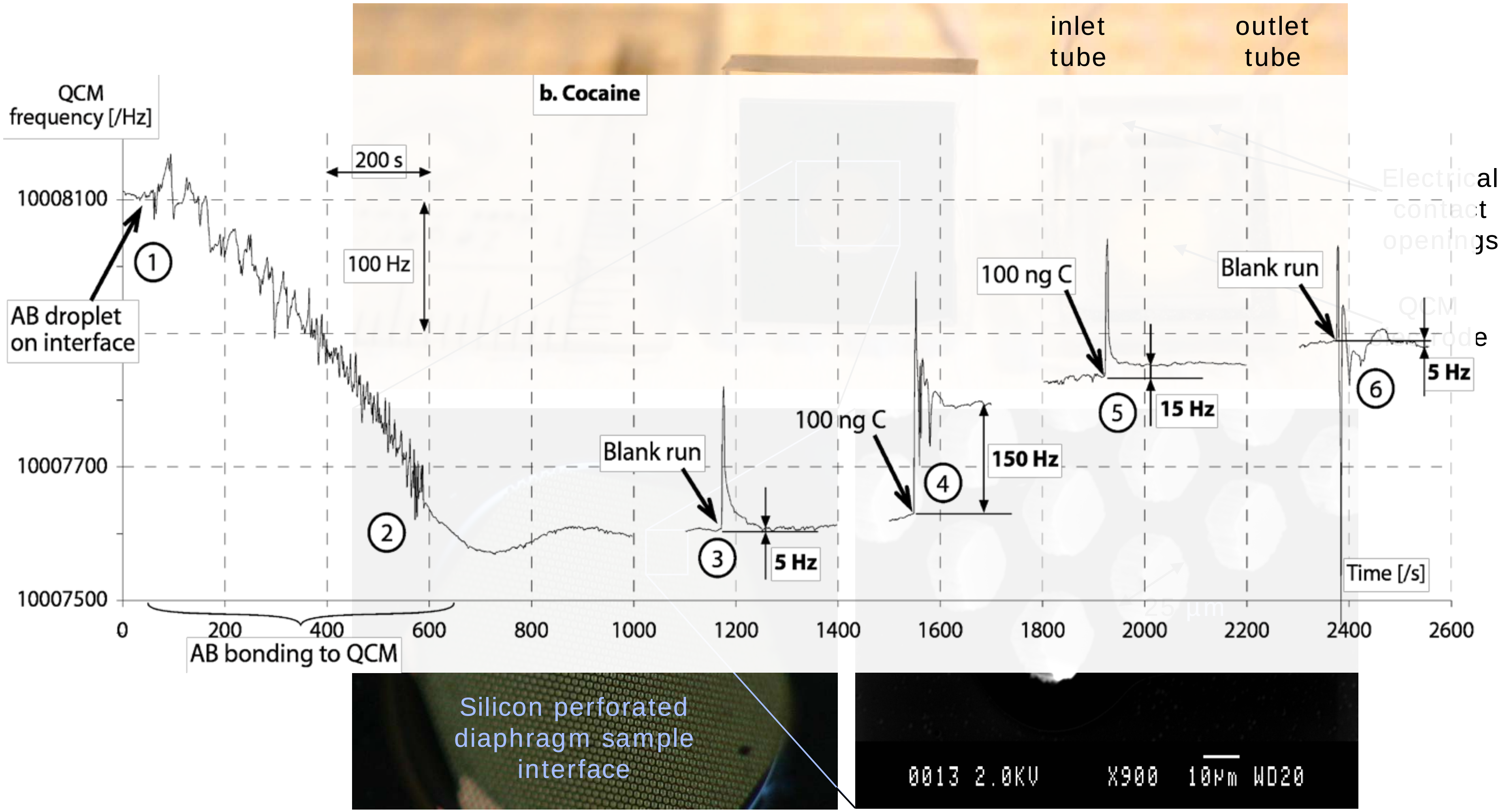
Phase 2 of miniaturisation



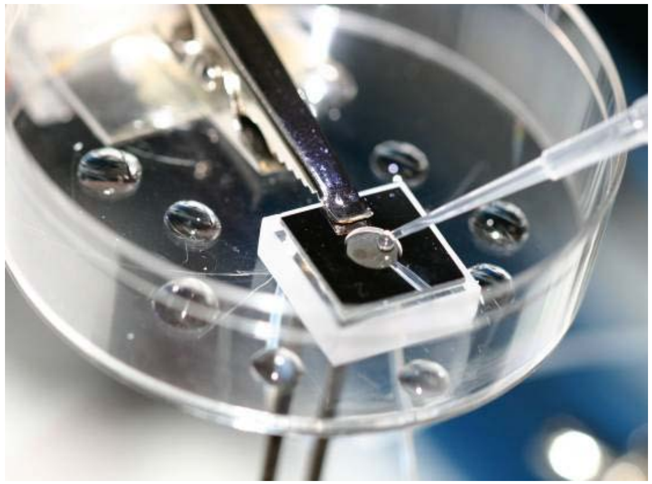
Phase 2 of miniaturisation



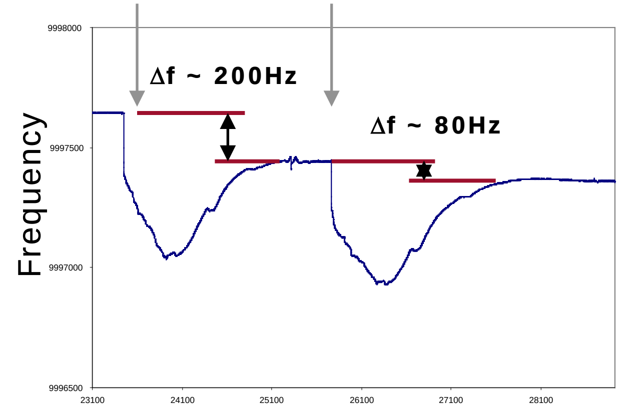
Cocaine detection

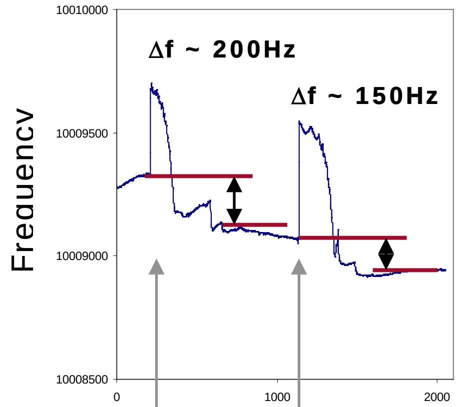


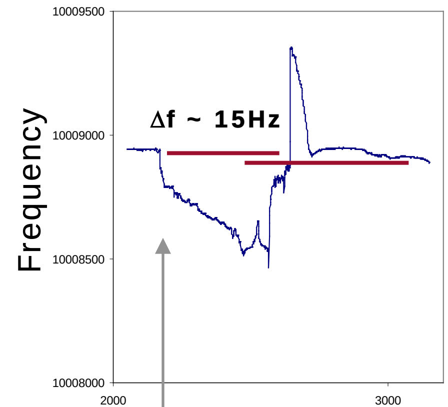
Norovirus detection



2x VLP on specific AB







AB binding BSA blocking

VLP on non-specific AB

Phase 2 additional enablers

Application demands small size

- Small amount of sample
- Portability
- Limited space at POC

Phys. laws of scaling

- Low inertia: fast response
- Short distance:
  - Fast transport
  - Diffusive transport
- Large surface/volume ratio:
  - Surface tension
  - Surface interactions
  - Laminar flow
  - ...

Diagnostic test benefits from downscaling

Microsystem manufacturing

- Semiconductor manufacturing
- Polymer microreplication
- Functional integration

⇩

Increased performance

- Novel functionality
- Faster system
- Low sample dispersion
- Sensor sensitivity

⇩

Decreased cost

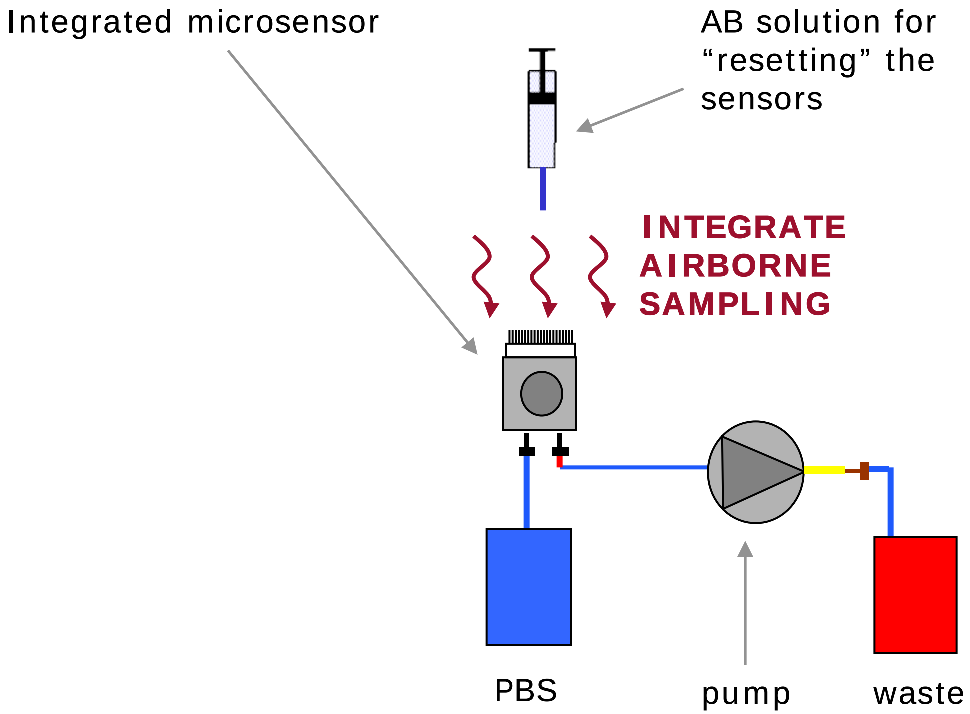
- Manufacturing cost
- Materials cost
- Consumables reduction
- Enabling disposables

Part 2 Device improvements

- Transport time interface → transducer is minimised
- Sample dispersion eliminated
- Buffer flow: 100μL/min → 2,5 μL/min
- Cost system assembly is further reduced

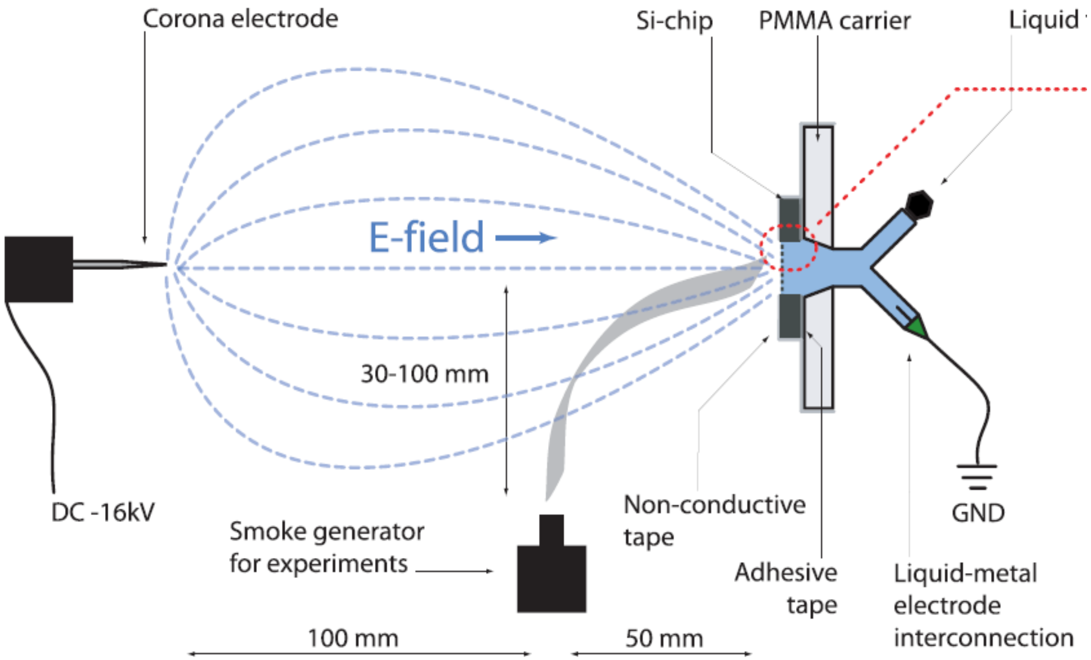
[Frisk et al., proc. IEEE MEMS, 2007]

Phase 3 of integration

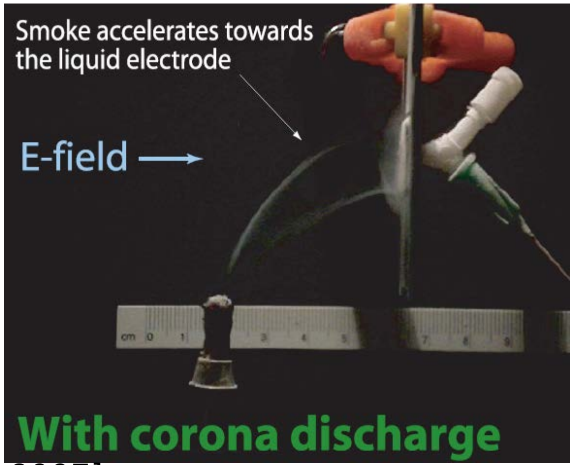


[Sandström et al., proc. MicroTAS, 2007]

ElectroHydroDynamic (EHD) airborne sample acquisition

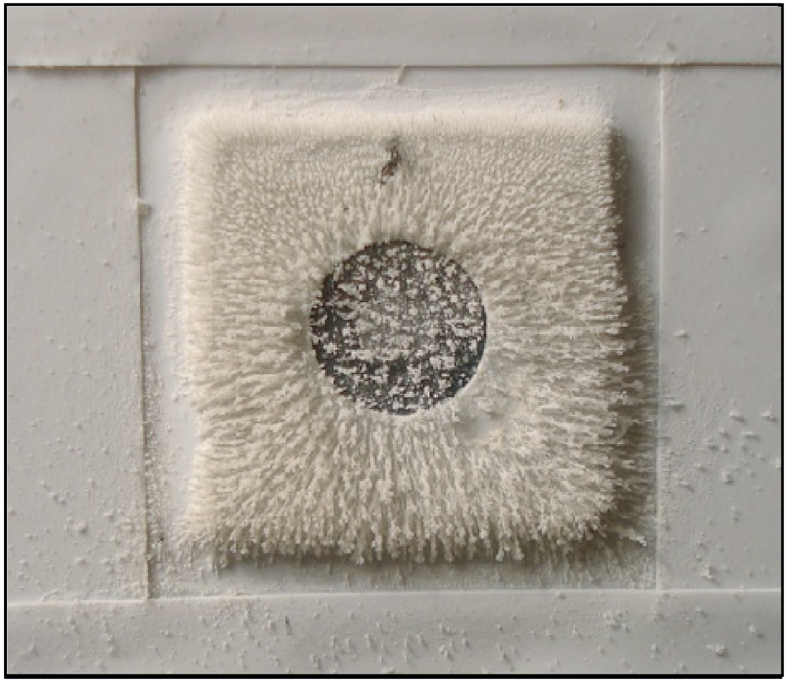


MOVIE

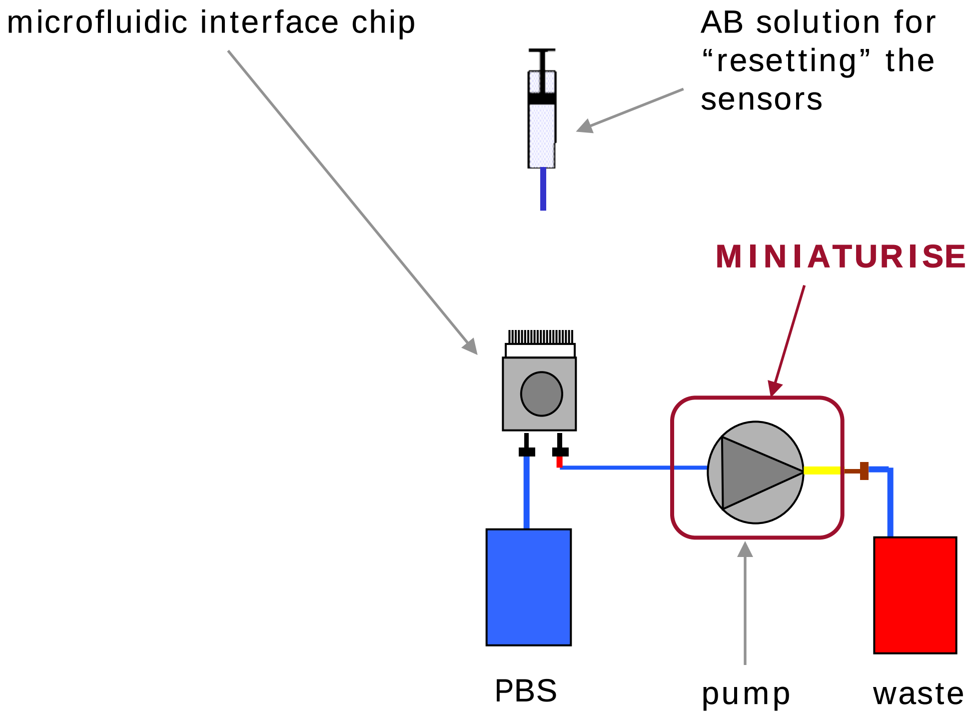


[Sandström et al., proc. MicroTAS, 2007]

EHD airborne particle collection



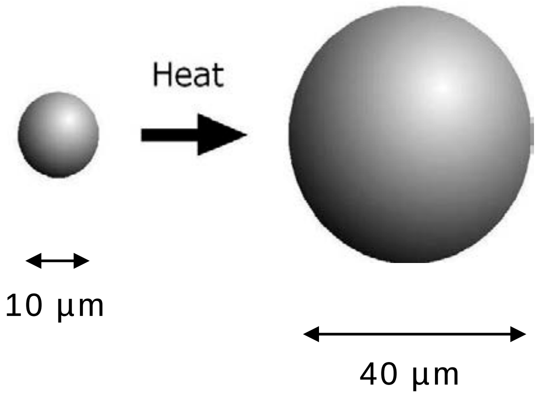
Phase 4 of miniaturisation



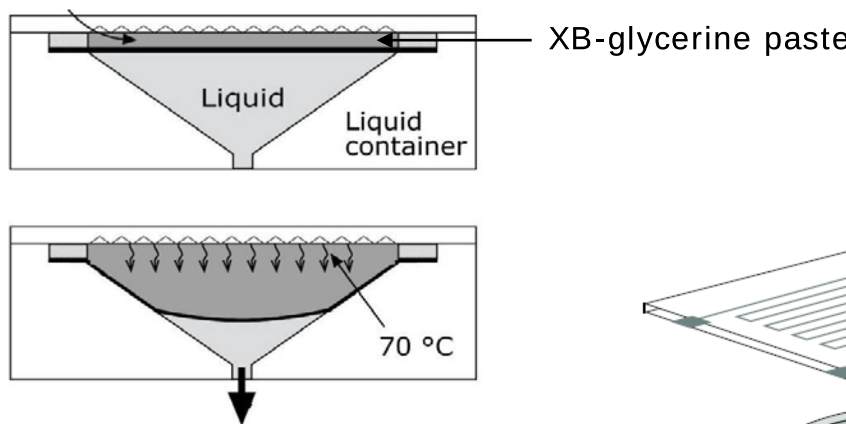
[Roxhed et al., *J. Micromech. Microeng*, (dec) 2006]

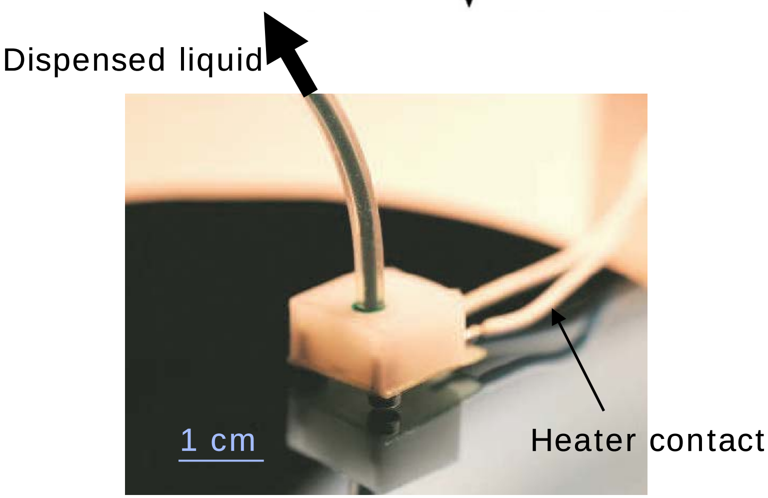
Integrated pumps and valves: Expandable Microspheres

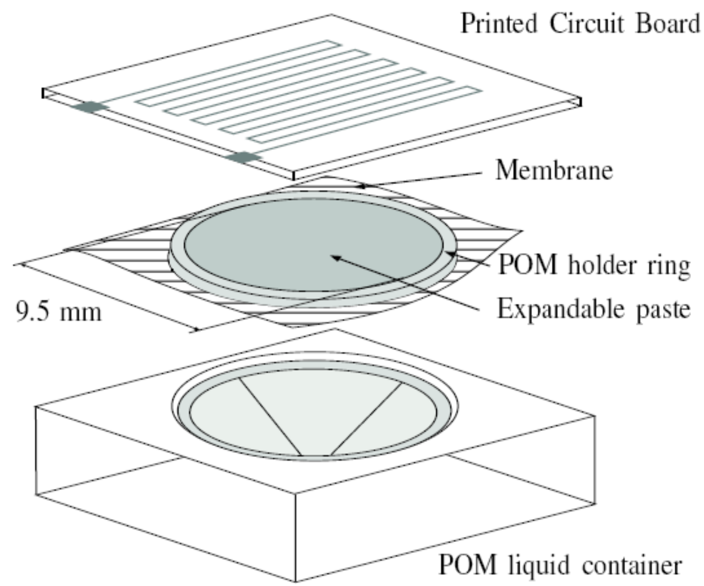
- Consist of polymer shells encapsulating liquid hydrocarbons
- Expancel® Microspheres expand upon heat
  - Shell softens,
  - Hydrocarbon changes phase,
  - Volume increases
- Properties:
  - Expansion up to 60 times
  - Expansion starts at 70°C
  - Chemically inert
  - Irreversible expansion



Continuous liquid dispensing



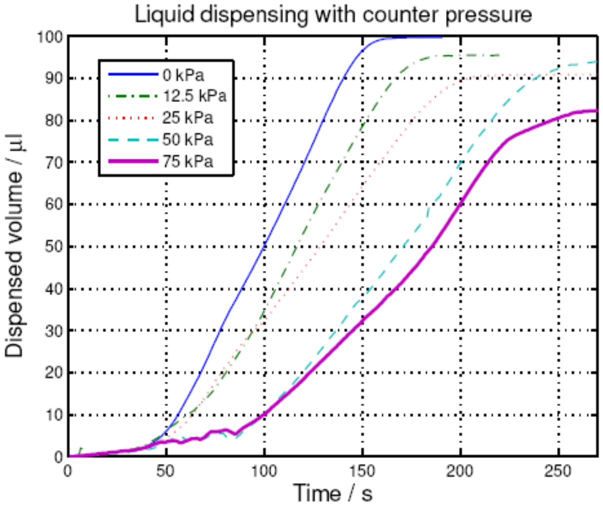




[Roxhed et al., *J. Micromech. Microeng*, (dec) 2006]

Continuous liquid dispensing

Key characteristics:
100 µL dispensed volume
Flow rate: 1-2400 µL/h
Delivery against 75kPa (=7.5m water)
Low cost



Dispensed volume / time

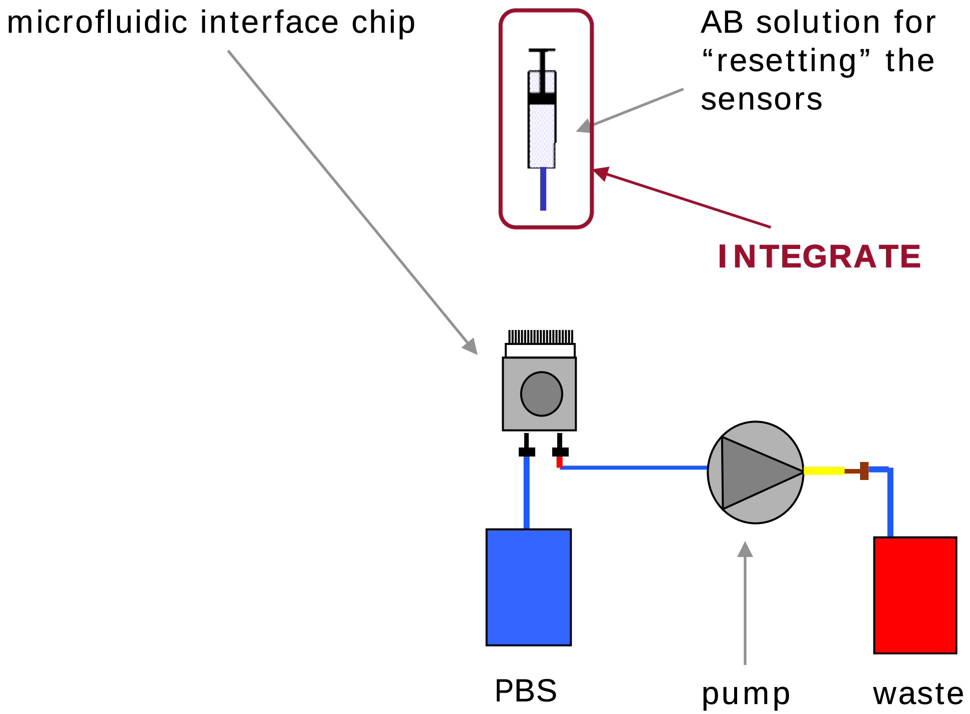
Unexpanded paste on heater

Paste freely expanded

Paste expanded in liquid container

[Roxhed et al., *J. Micromech. Microeng*, (dec) 2006]

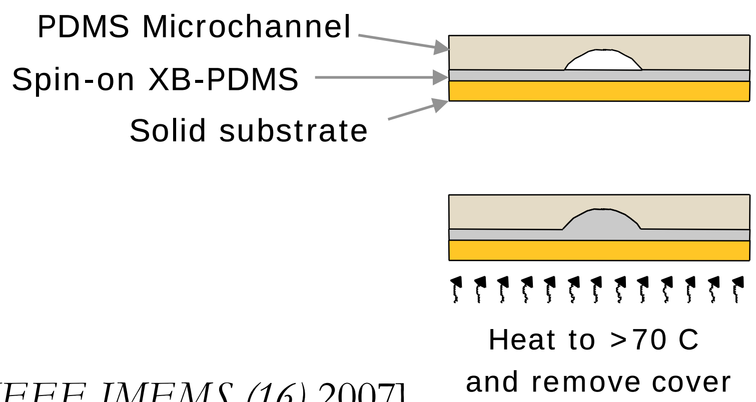
Phase 5 of miniaturisation

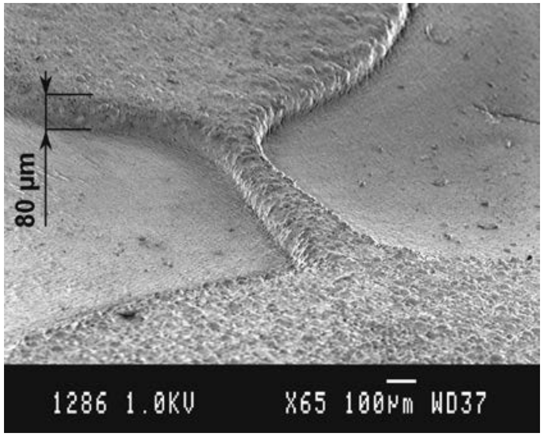


[Samel et al., *Biomedical Microdevices*, 9 (1), 2007]

Expandable microspheres in PDMS

- Mixing PDMS and Expancel® microspheres: XB-PDMS
  → A thermally responsive PDMS composite
  - Large expansion (> 100%)
  - Highly elastomeric
  - Non-toxic and chemically inert
  - Allows for e.g. soft lithography, casting, spinning…
  - Highly integratable actuator

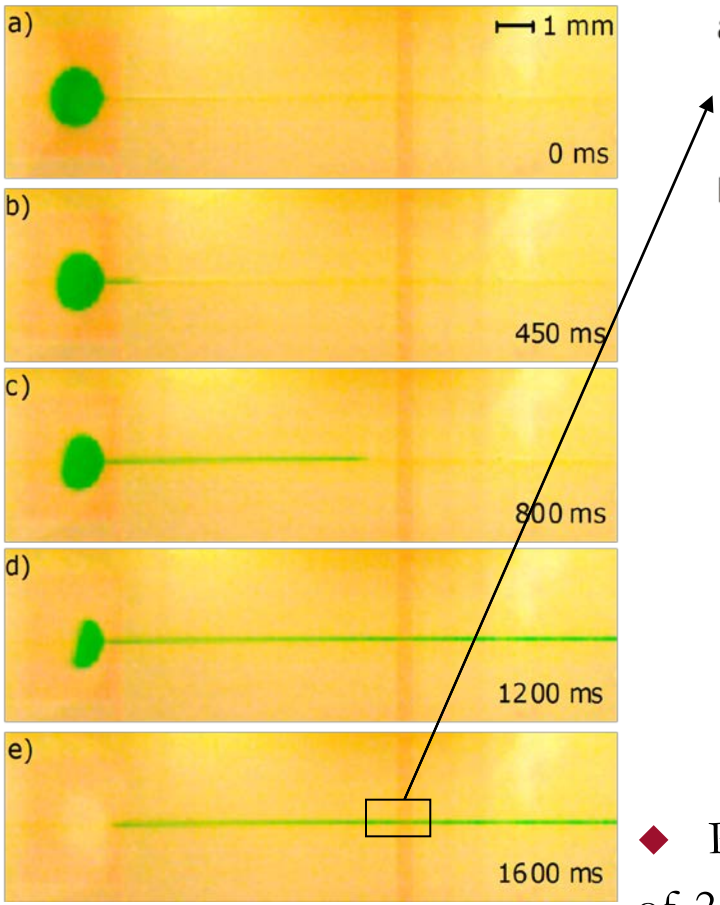




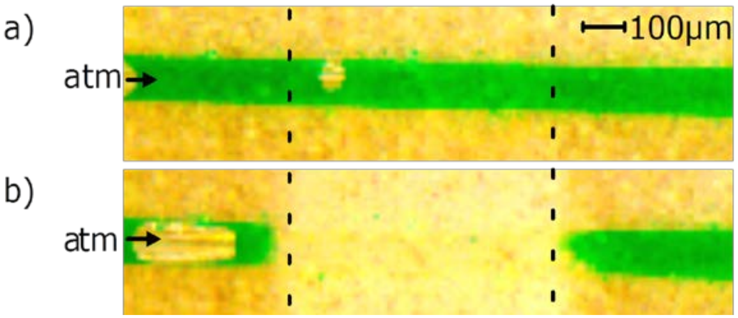
[Samel et al., *IEEE JMEMS (16)* 2007]

Single-use pumps and valves

- Pump



- Valve

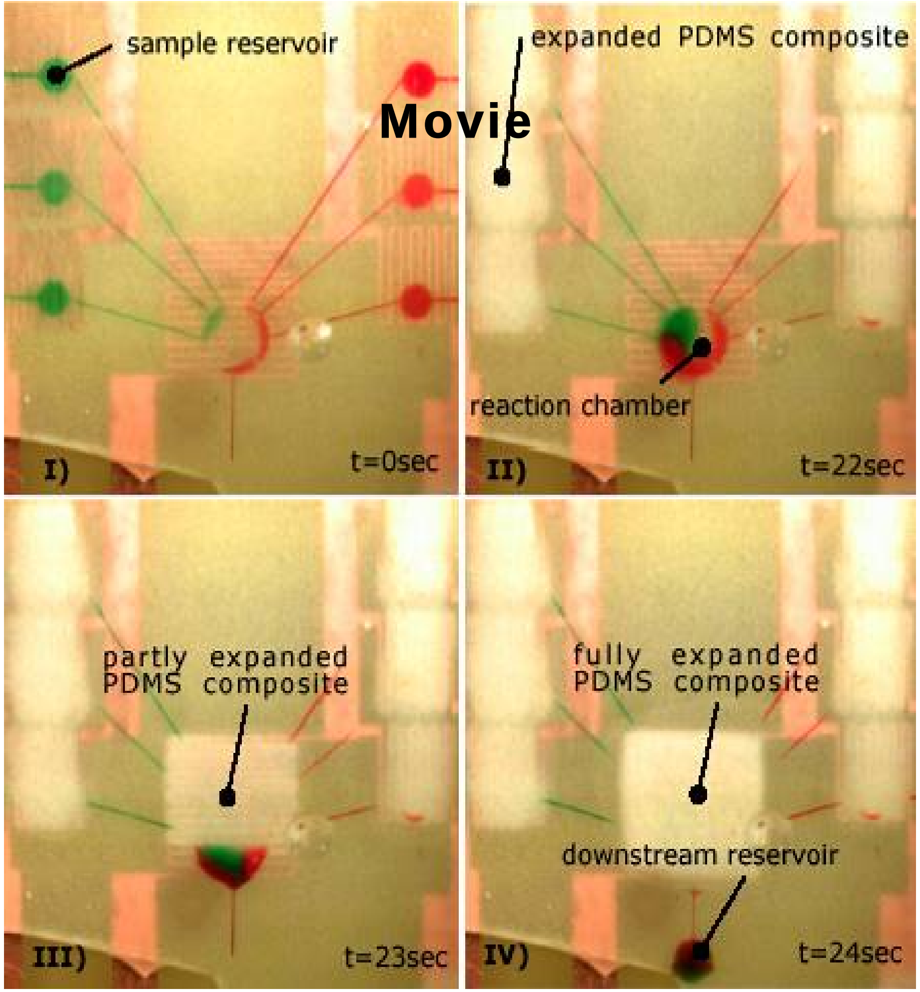


- Picture sequence of the valve in its open (a) and closed (b) state.

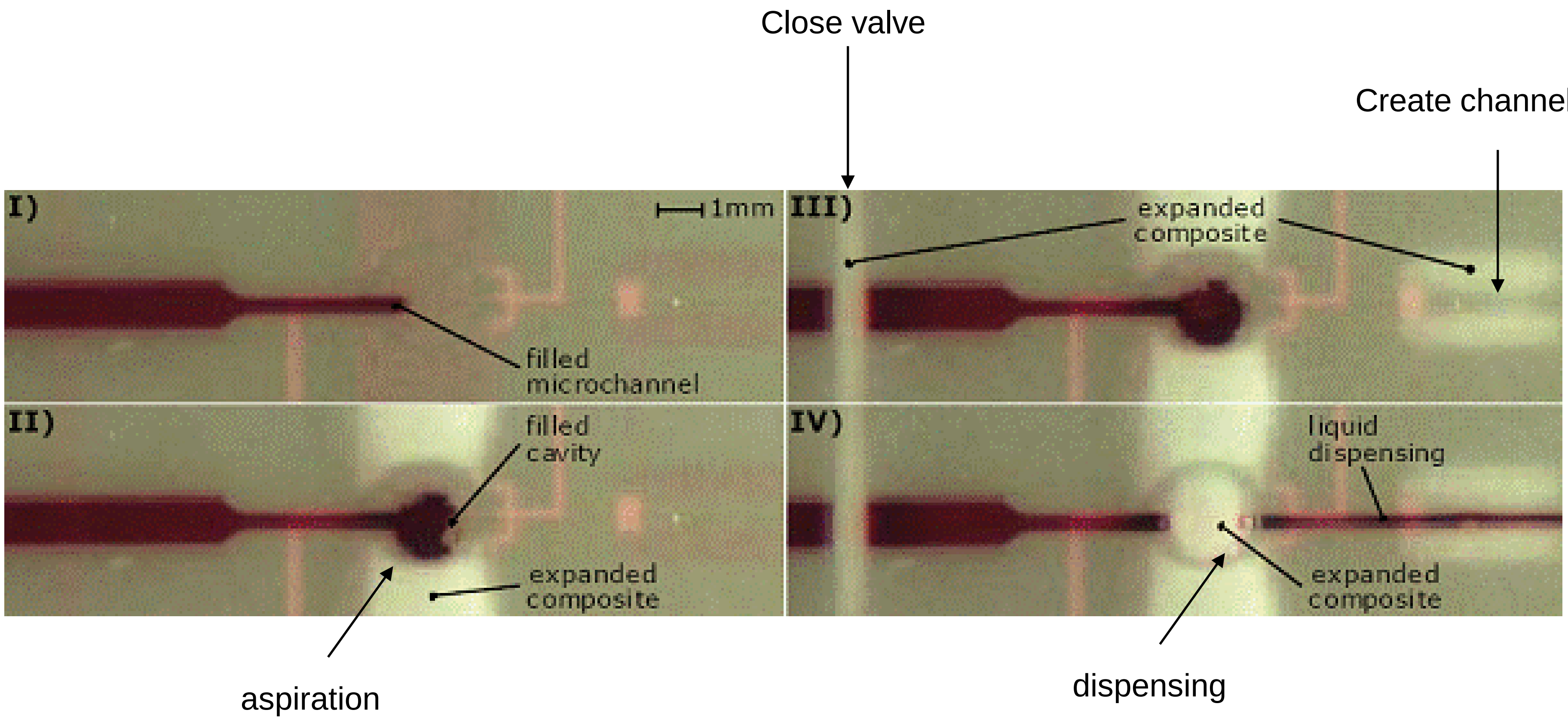
[Samel et al., *Biomedical Microdevices*, 9 (1), 2007]

- Picture sequence showing the release of 25nl of liquid from a reservoir

Dosing, transportation and merging of nanoliter volumes



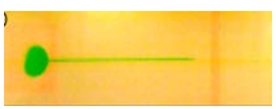
On-chip fluid loading, storage and dispensing

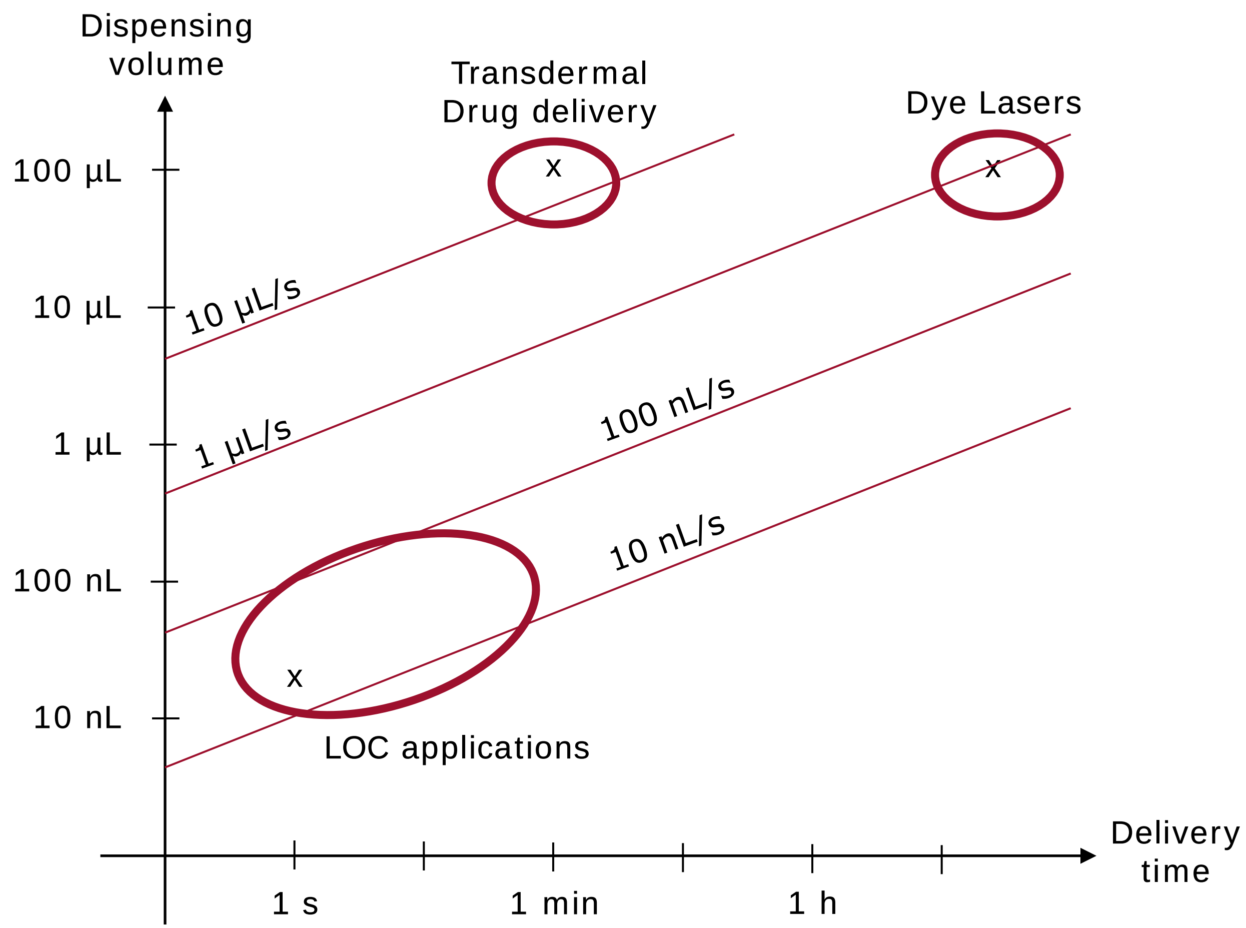


[Samel et al., proc. MicroTAS, 2007]

MOVIE

XB microfluidic dispensers





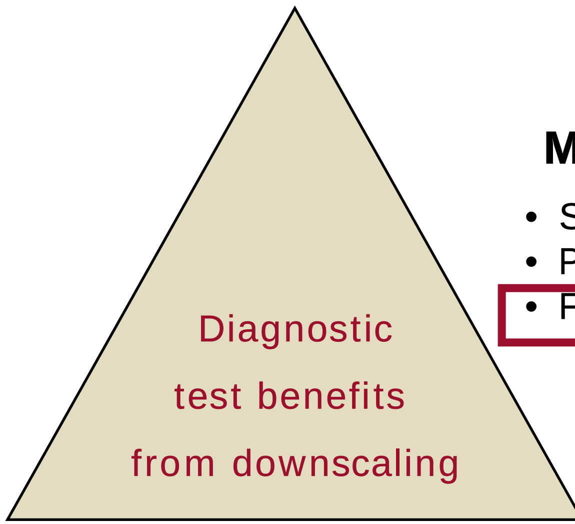
Phase 2 additional enablers

Application demands small size

- Small amount of sample
- Portability
- Limited space at POC

Phys. laws of scaling

- Low inertia: fast response
- Short distance:
  - Fast transport
  - Diffusive transport
- Large surface/volume ratio:
  - Surface tension
  - Surface interactions
  - Laminar flow
  - ...



Microsystem manufacturing

- Semiconductor manufacturing
- Polymer microreplication
- Functional integration

Increased performance

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Microfluidic solutions for label-free diagnostic sensors