Aalto University

Microfluidic components 2021

sami.franssila@aalto.fi

Contents

- Valving
- Pumping

} flow control

- CE (capillary electrophoresis
- Microreactors

} applications

- Package and connectors

} interfacing

Basic geometries:straight channel

-separation channel

-mixer

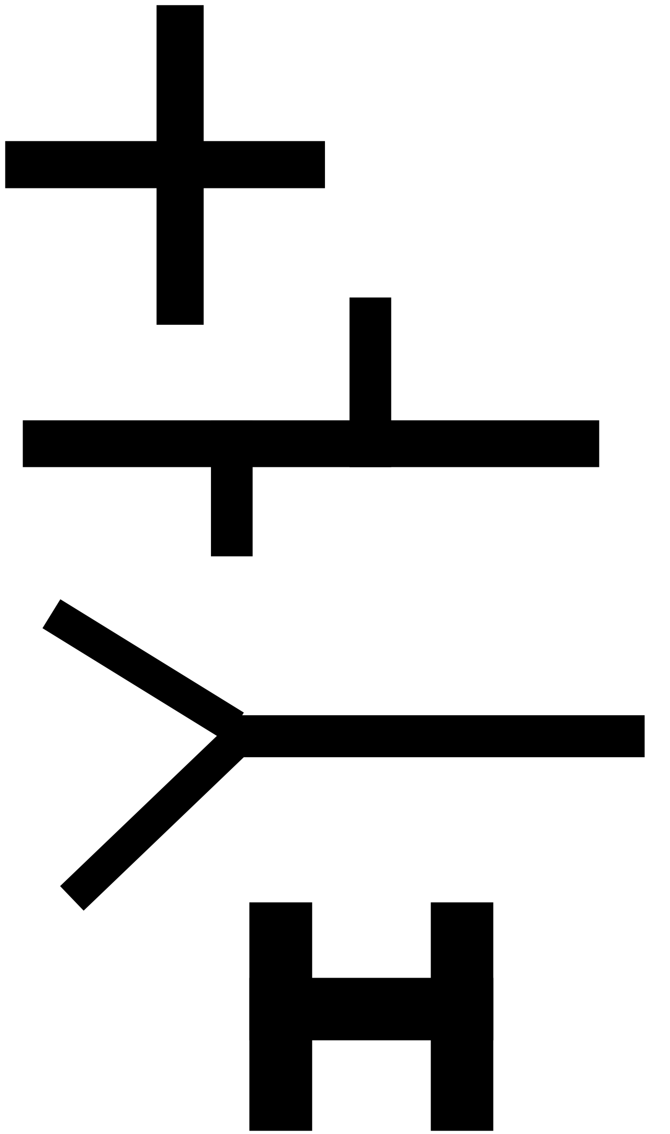
-microreactor

-...

Typical channel dimensions:

Widths 50-100 µm
Depths 10-100 µm
(a lot of variability !)

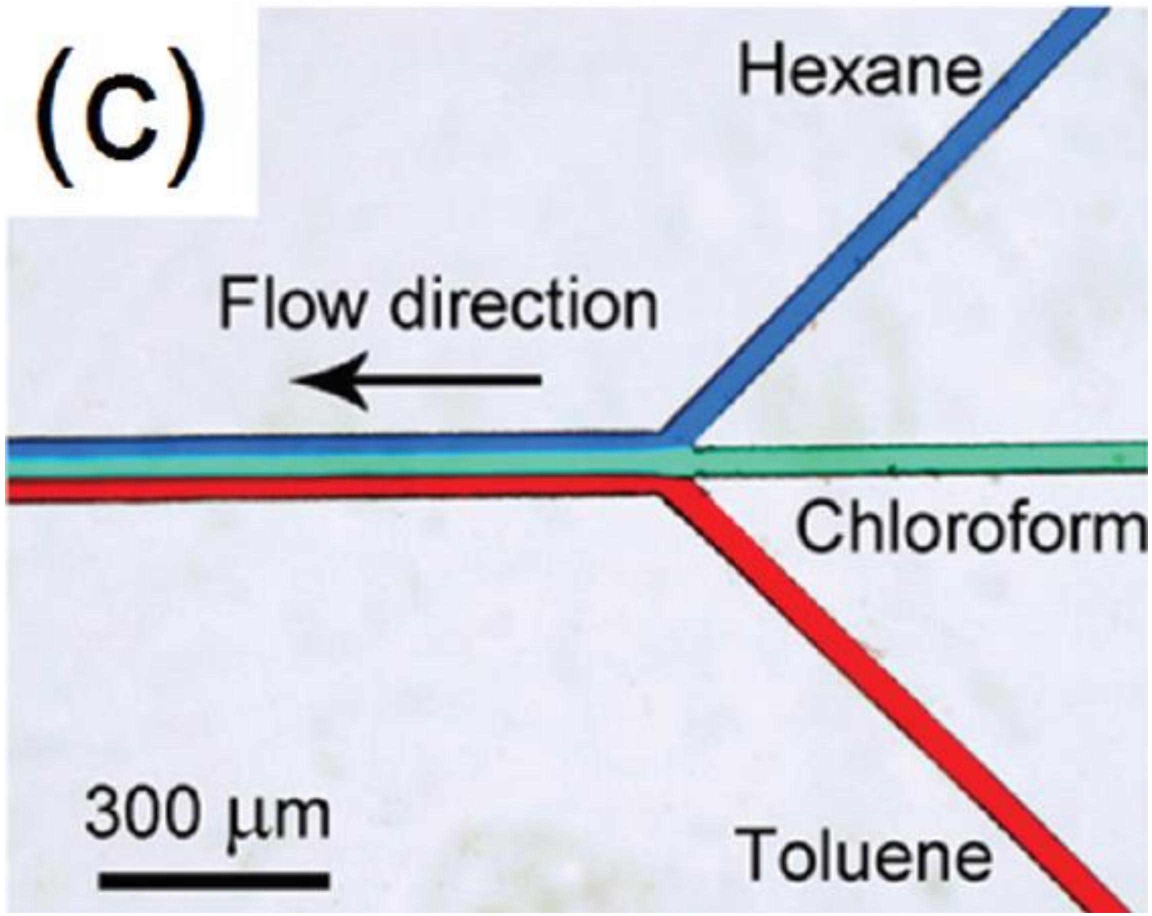
Basic geometries: X,T,Y,H



Applications:

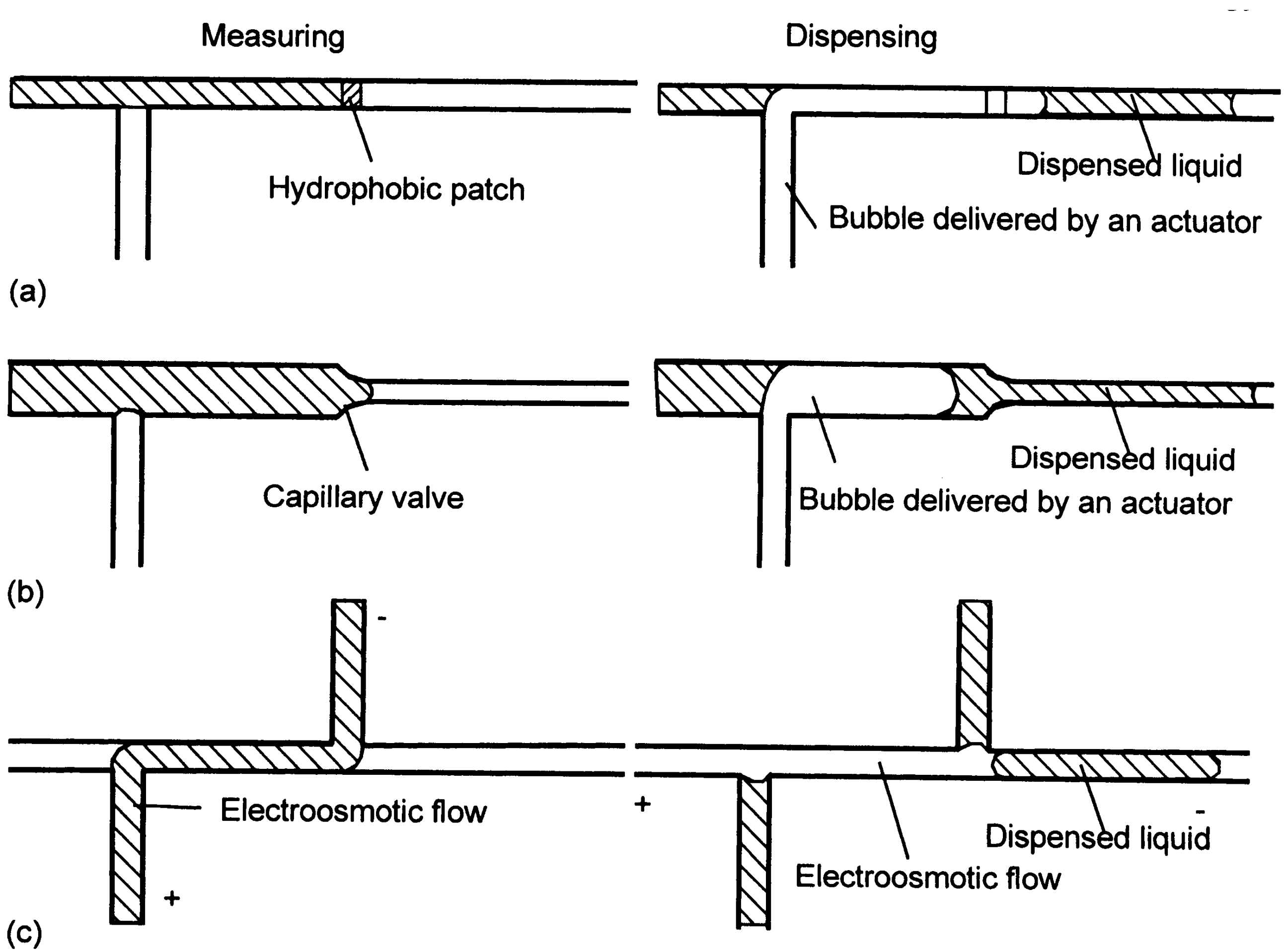
- CE injectors
- mixers
- filters
- reactors

Laminar flow device



Ren, K.; Dai, W.; Zhou, J.; Su, J.; Wu, H. Proc. Natl. Acad. Sci. U.S.A. 2011, 108, 8162–8166.

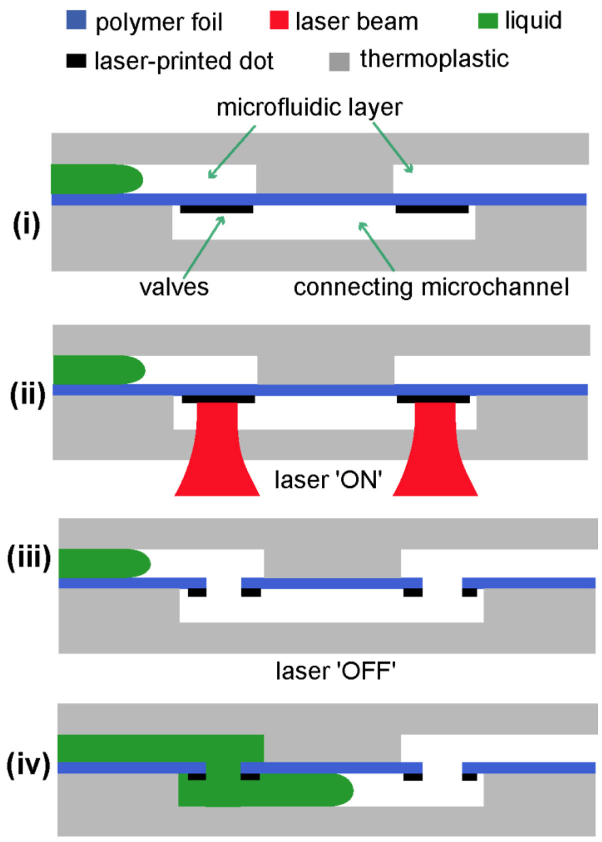
Dispensers



Nguyen p.

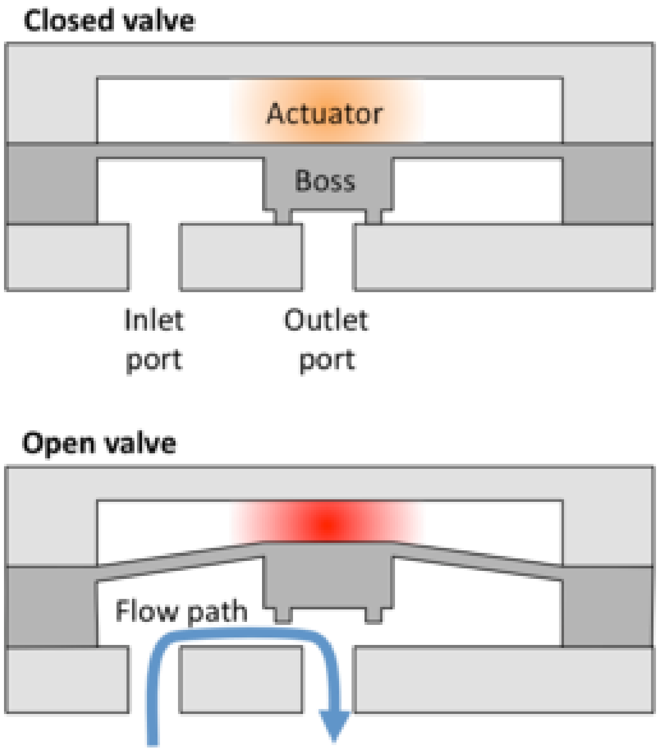
Valves

One shot valve



Garcia-Cordero et al: Lab on a Chip · October 2010

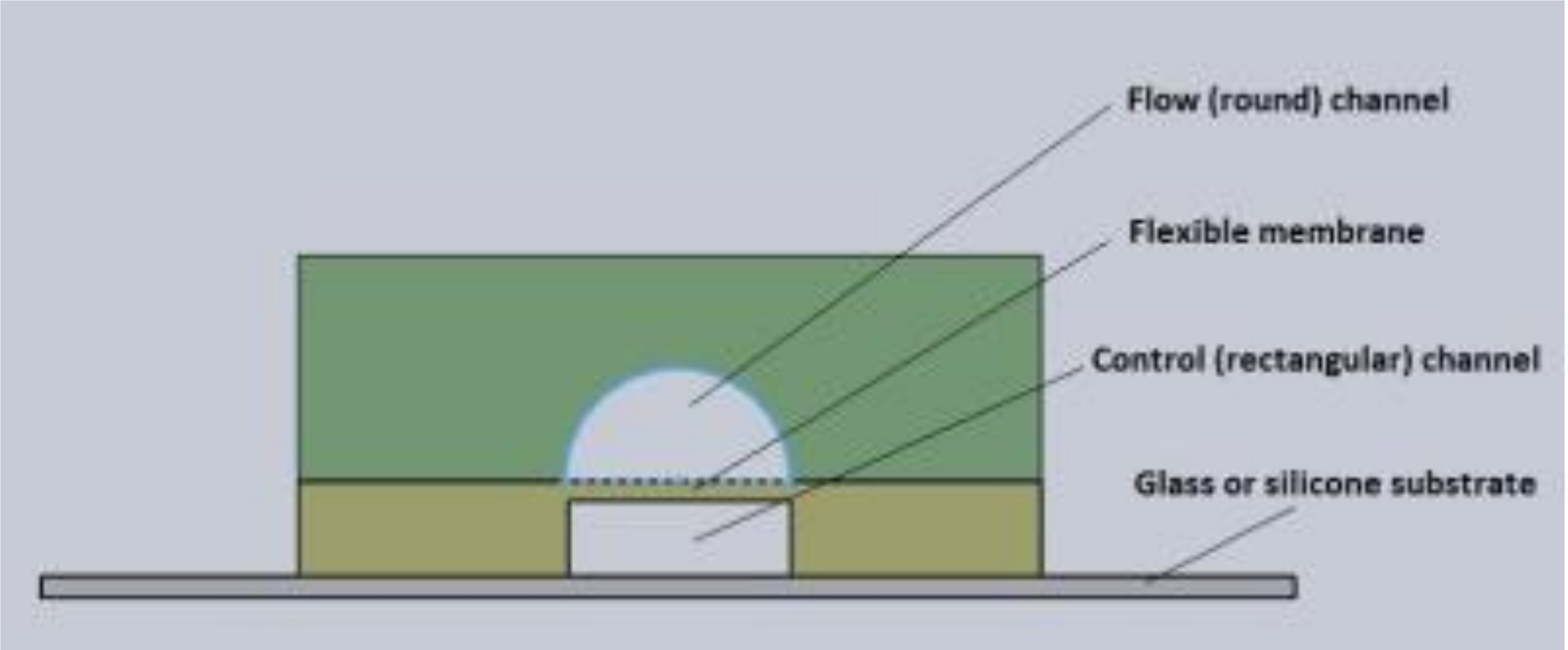
Open and close valve



Wikipedia

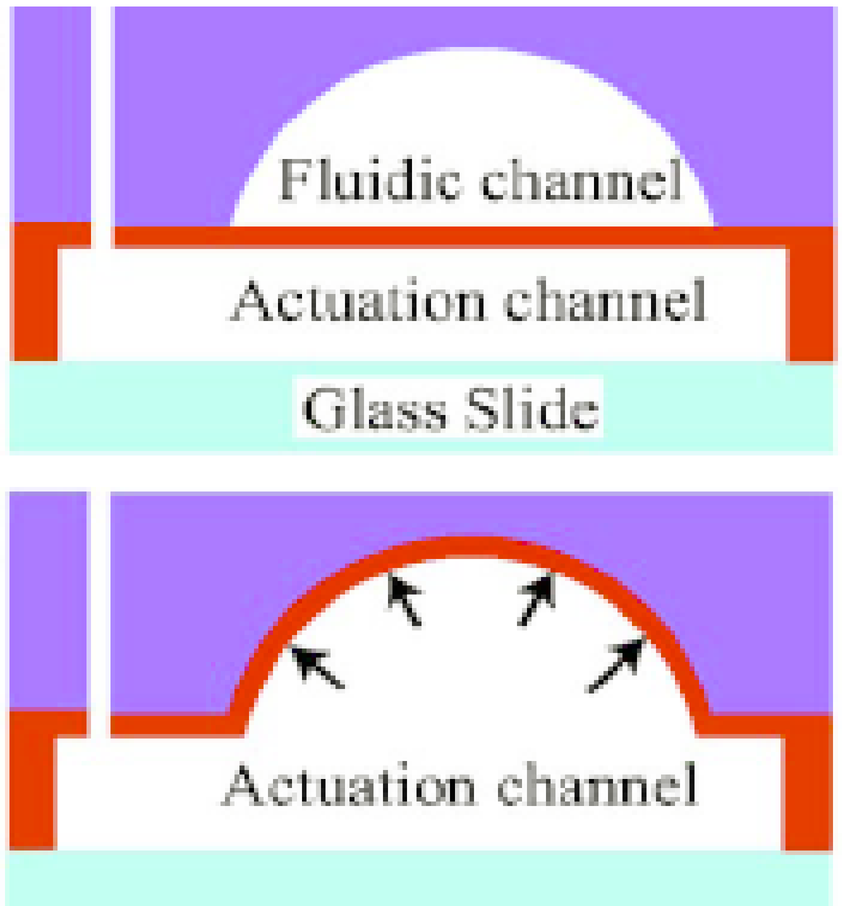
Passive valves	Active valves
• mechanical	pneumatic
• geometric	thermopneumatic
• hydrophobic	phase-change
	electrostatic
	piezoelectric
	thermal expansion

Quake valve (diaphragm valve)

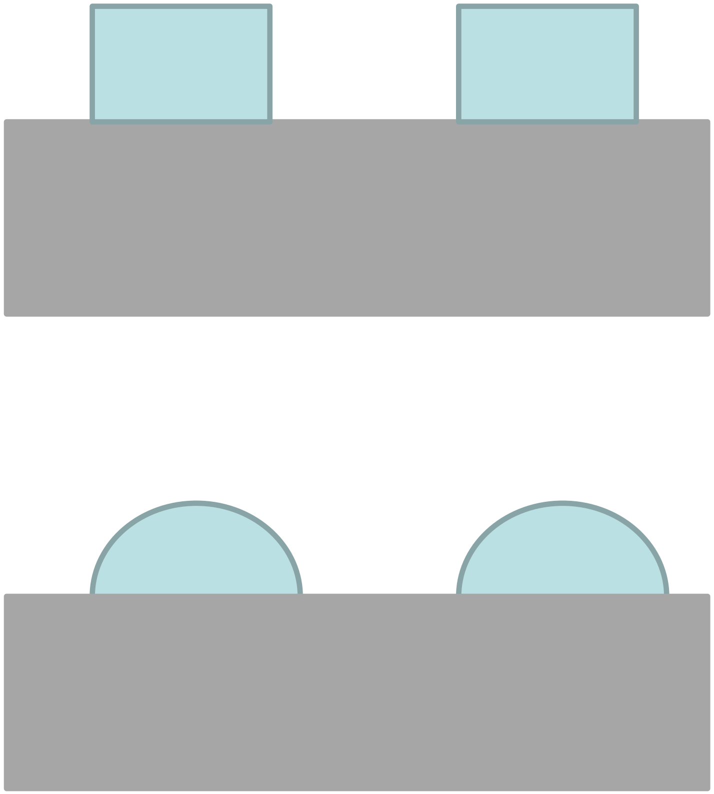


After Stephen Quake, Stanford professor and founder of Fluidigm.

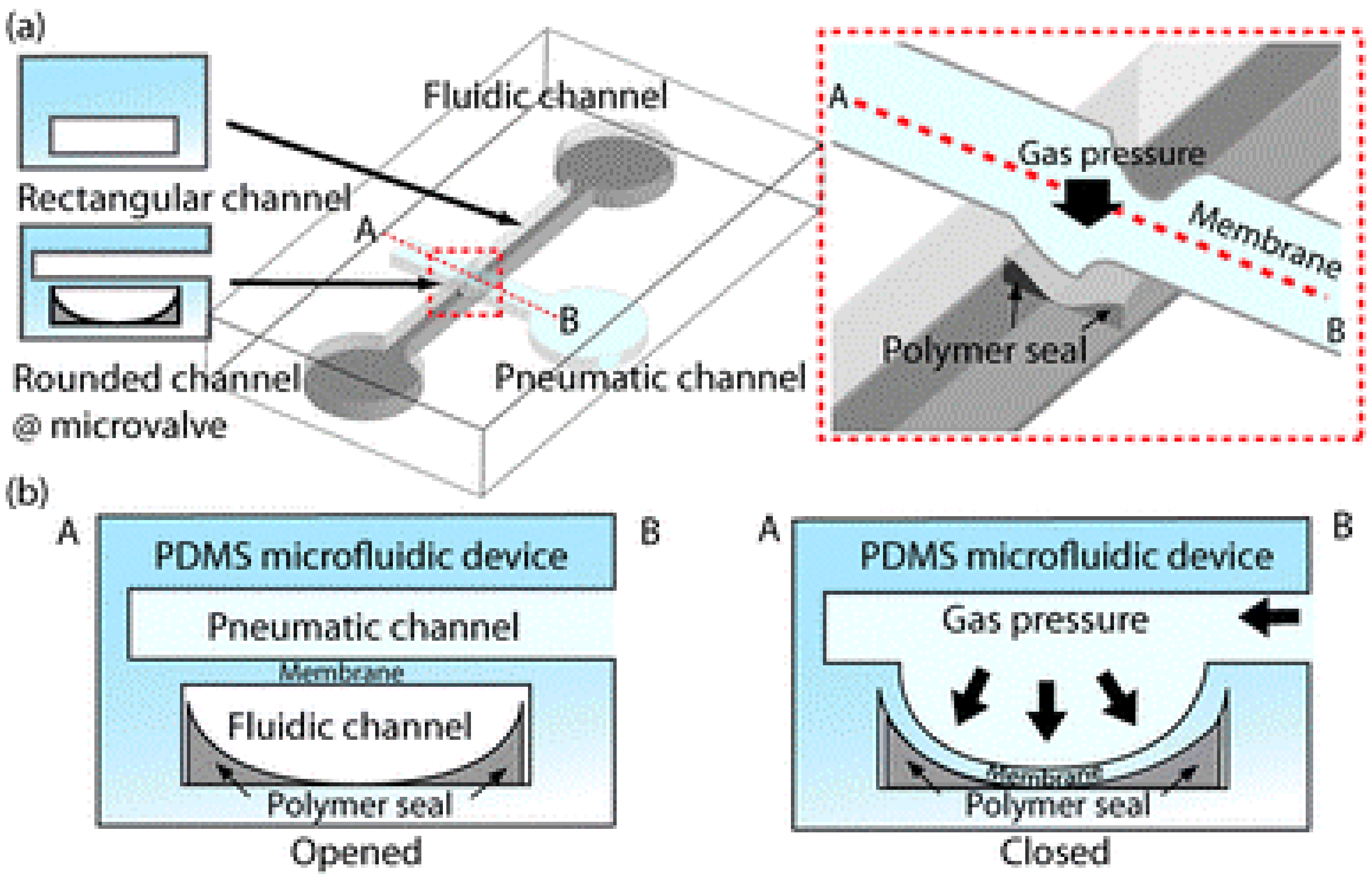
Why semicircular channel ?



How to make semicircular channel ? Resist flow > T_g

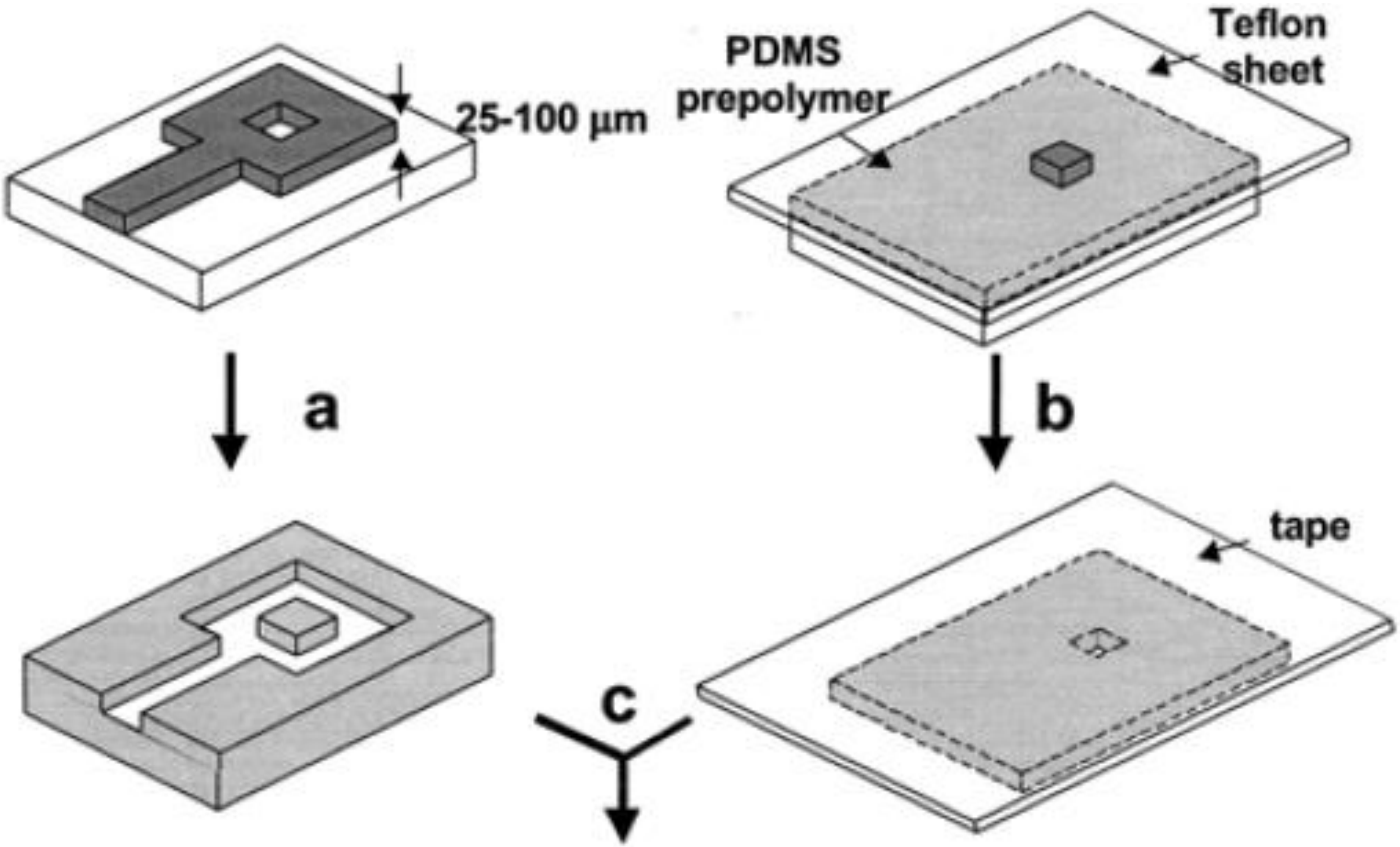


PDMS membrane valve



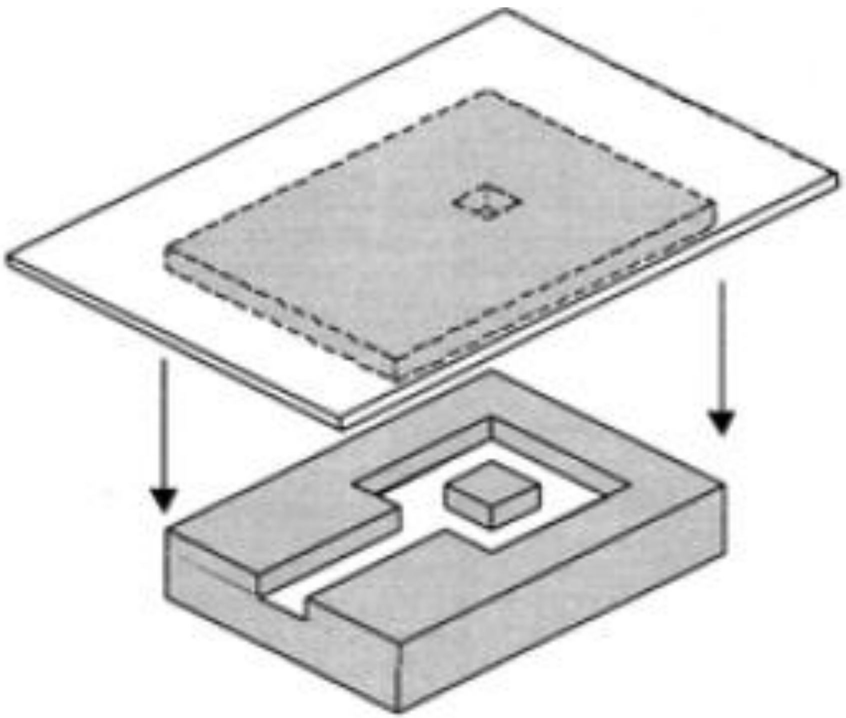
Lab Chip, 2010, **10**, 2814-2817

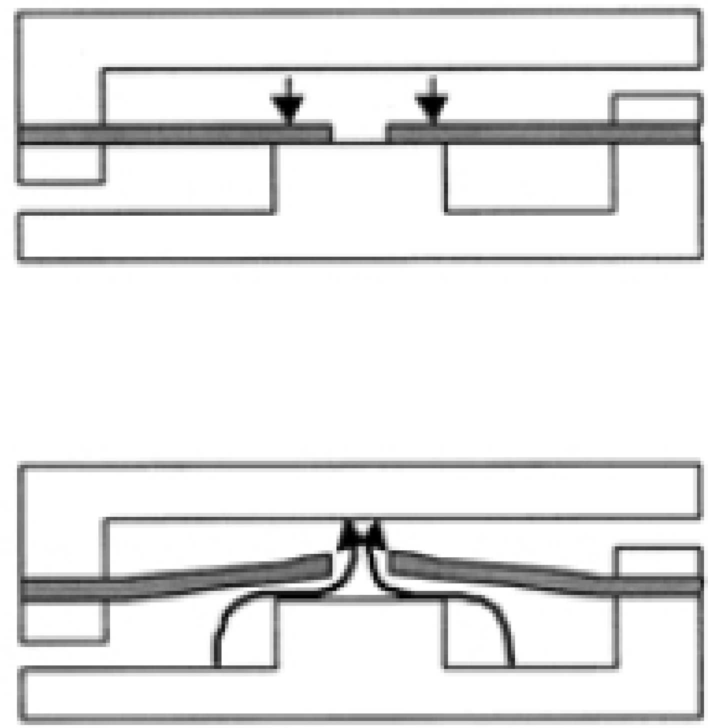
Flap valve by PDMS molding



Jeon, N. L., D. T. Chiu, C. J. Wargo, H. K. Wu, I. S. Choi, J. R. Anderson, and G. M. Whitesides, 2002, Biomed. Microdevices 4, 117.

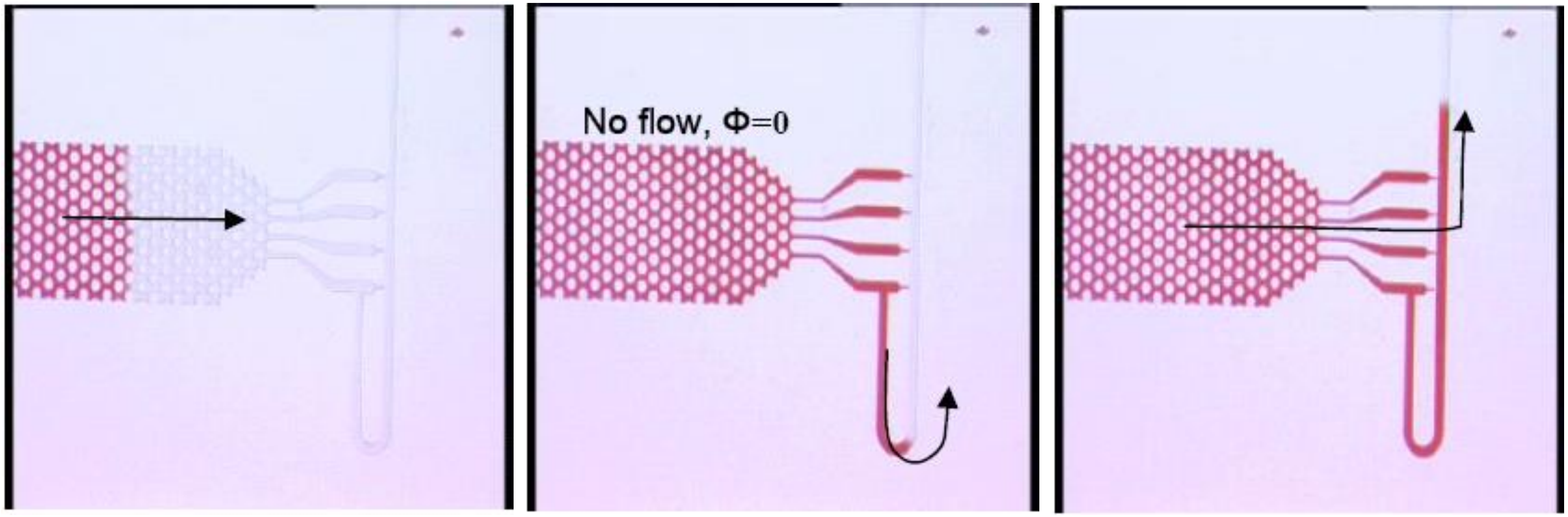
Flap-valve (2)





Jeon, N. L., D. T. Chiu, C. J. Wargo, H. K. Wu, I. S. Choi, J. R. Anderson, and G. M. Whitesides, 2002, Biomed. Microdevices **4**, 117.

Geometric valves



(a) (b) (c)

Capillary pump controls the capillary pressure and rate of flow.

Rapid constriction of the flow channel will stop the flow.

Side channel offers timing of flow.

Vuk Siljegovic, Nenad Milicevic, Patrick Griss Transducers 2005, p. 1565

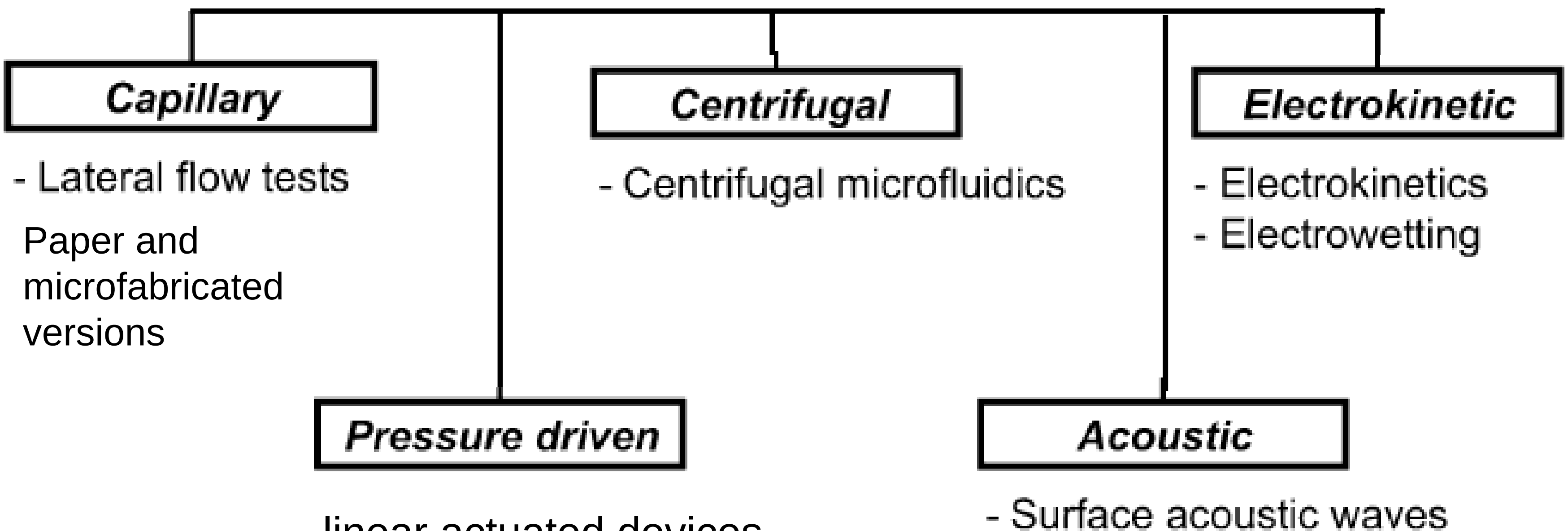
Pumps

- bubble pumps
- membrane pumps
- diffuser pumps
- rotary pumps
- electrohydrodynamic
- electro-osmotic
- ultrasonic pumps
- vacuum pumps

Criteria:

-size, miniaturization potential
-power consumption
-flow rate
-reliability

Pumping operating principles

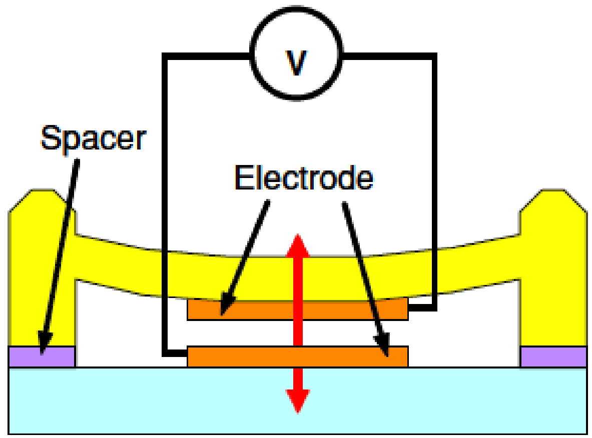


Paper and microfabricated versions

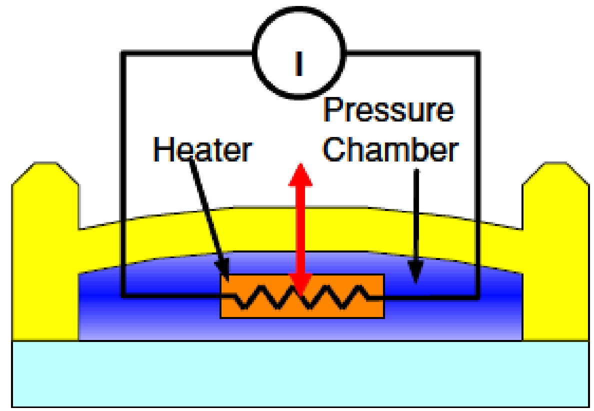
-linear actuated devices
-pressure drives laminar
-large scale integration
-segmented flow
-

Chem. Soc. Rev., 2010, 39, 1153

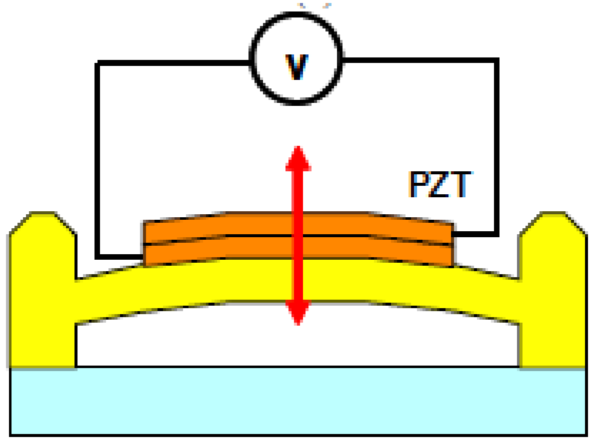
Diaphragm pumps: actuation



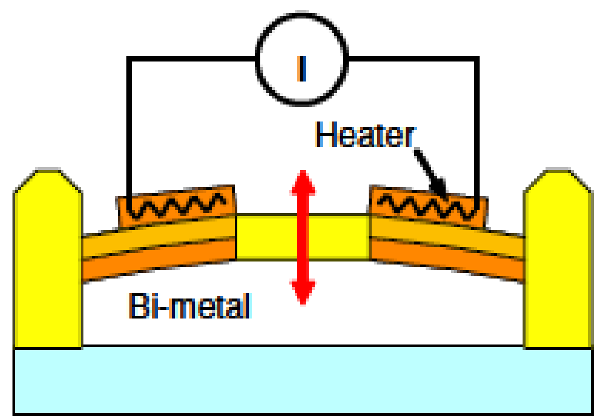
electrostatic



Phase change



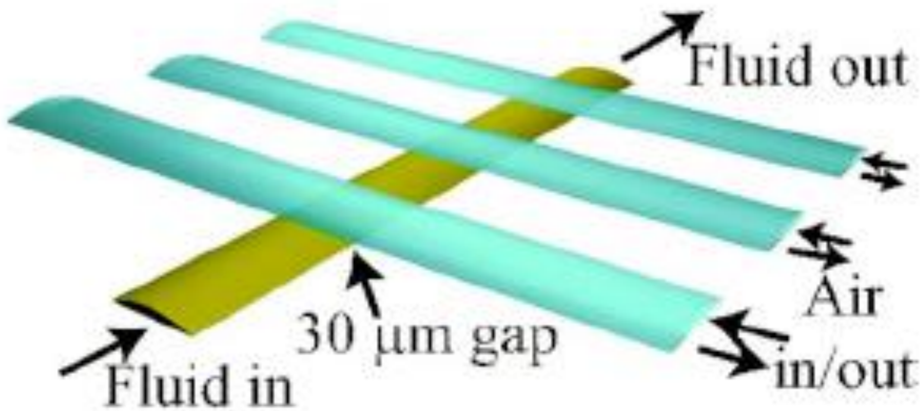
piezoelectric

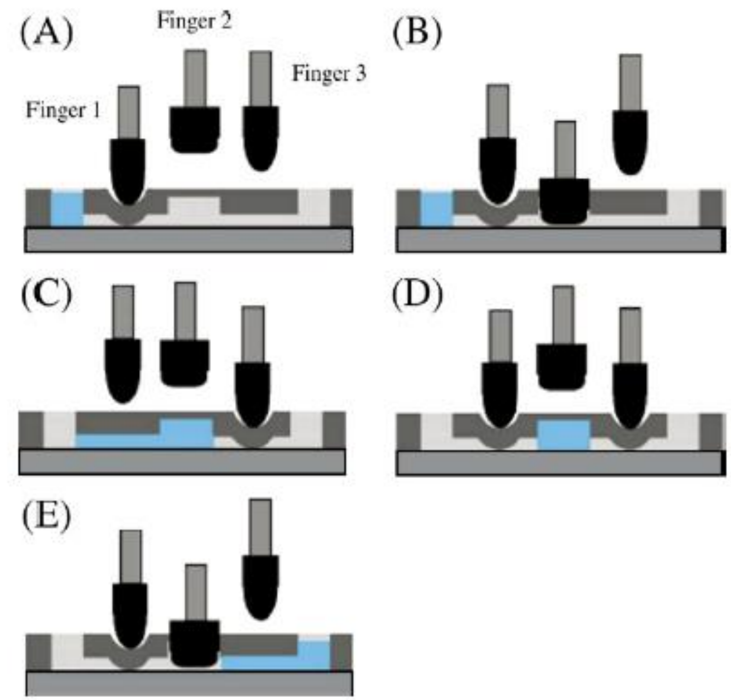


Thermal expansion

J. Micromech. Microeng. **16** (2006) R13–R39

Peristaltic pump = 3 valves in series



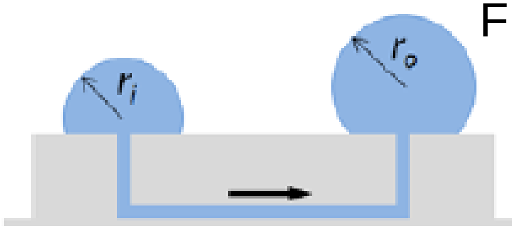


Unger, M. A., H. P. Chou, T. Thorsen, A. Scherer, and S. R. Quake, 2000, Science **288**, 113.

Pilarski PM, Adamia S, Backhouse CJ. An adaptable microvalving system for on-chip polymerase chain reactions. J Immunol Methods 2005;305:48–58.

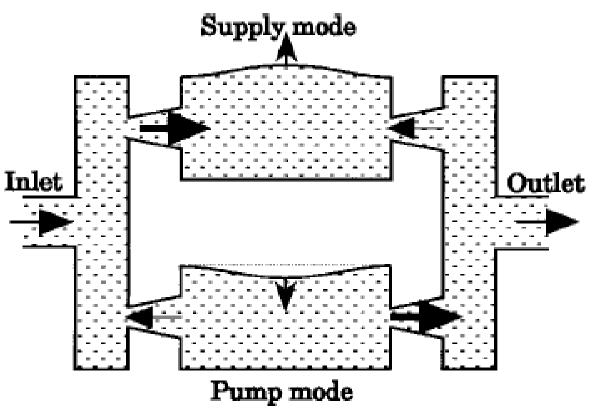
Pumps without moving parts

Flow is from higher Laplace pressure to lower.



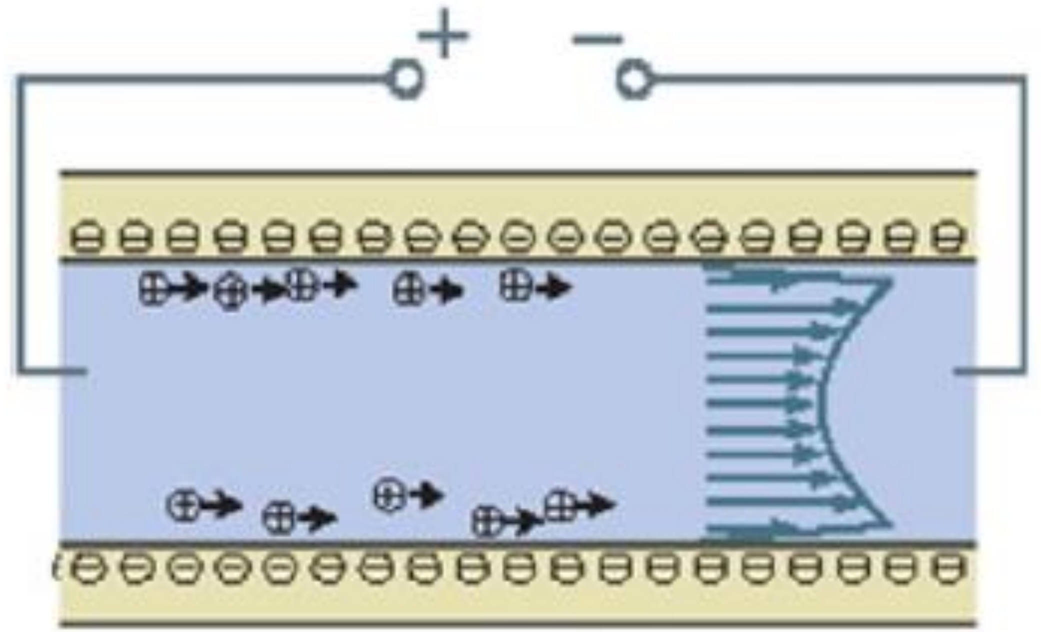
Surface tension driven pump

J. Micromech. Microeng. 18 (2008) 087002 (5pp)



Nozzle-diffuser pump,

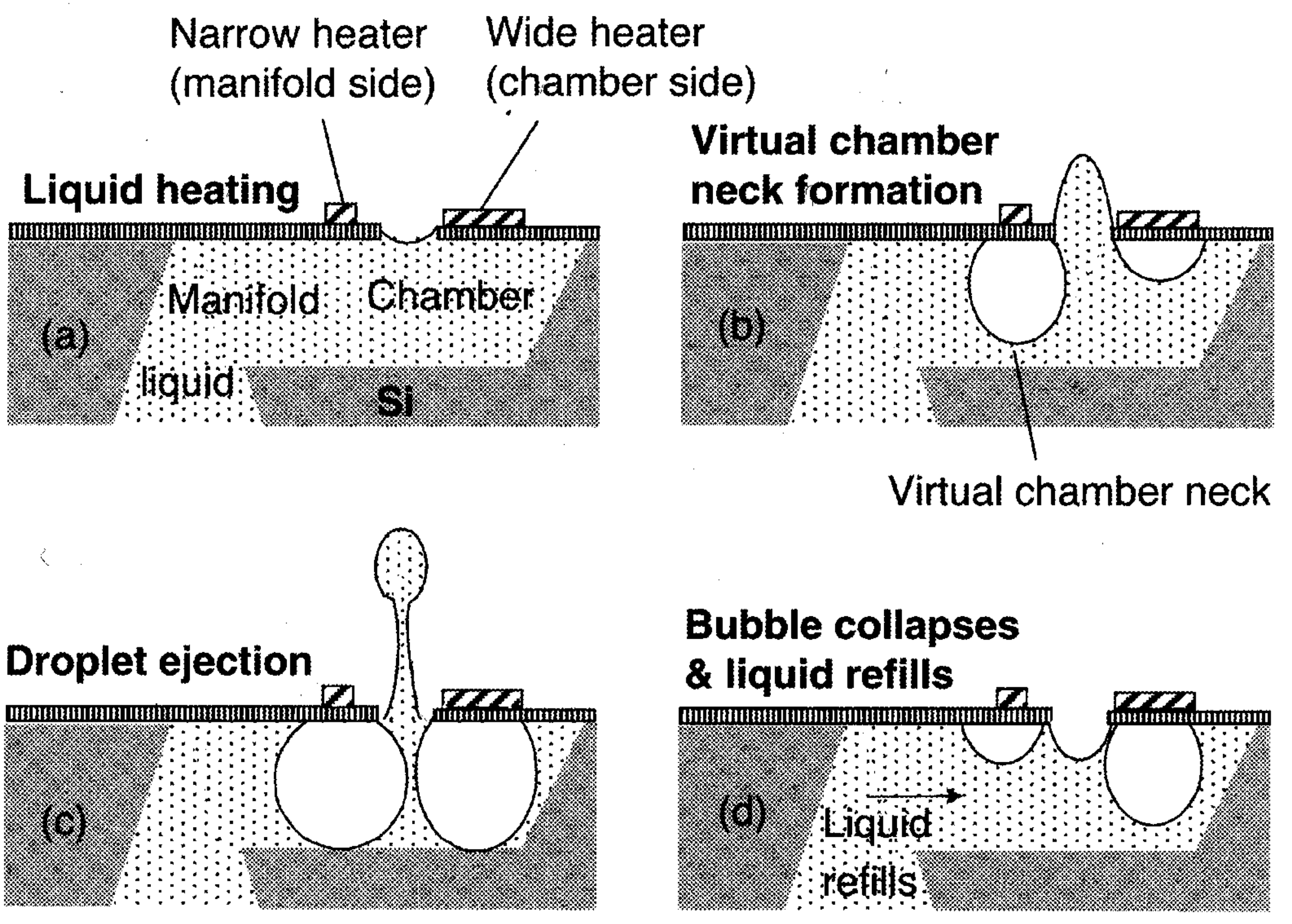
Olsson, Stemme 1997



Electro-osmotic pump

J K Luo[1,2], Y Q Fu[2,3], Y Li[4], X Y Du[2], A J Flewitt[2], A J Walton[4] and W I Milne[2]

Thermal ink jet

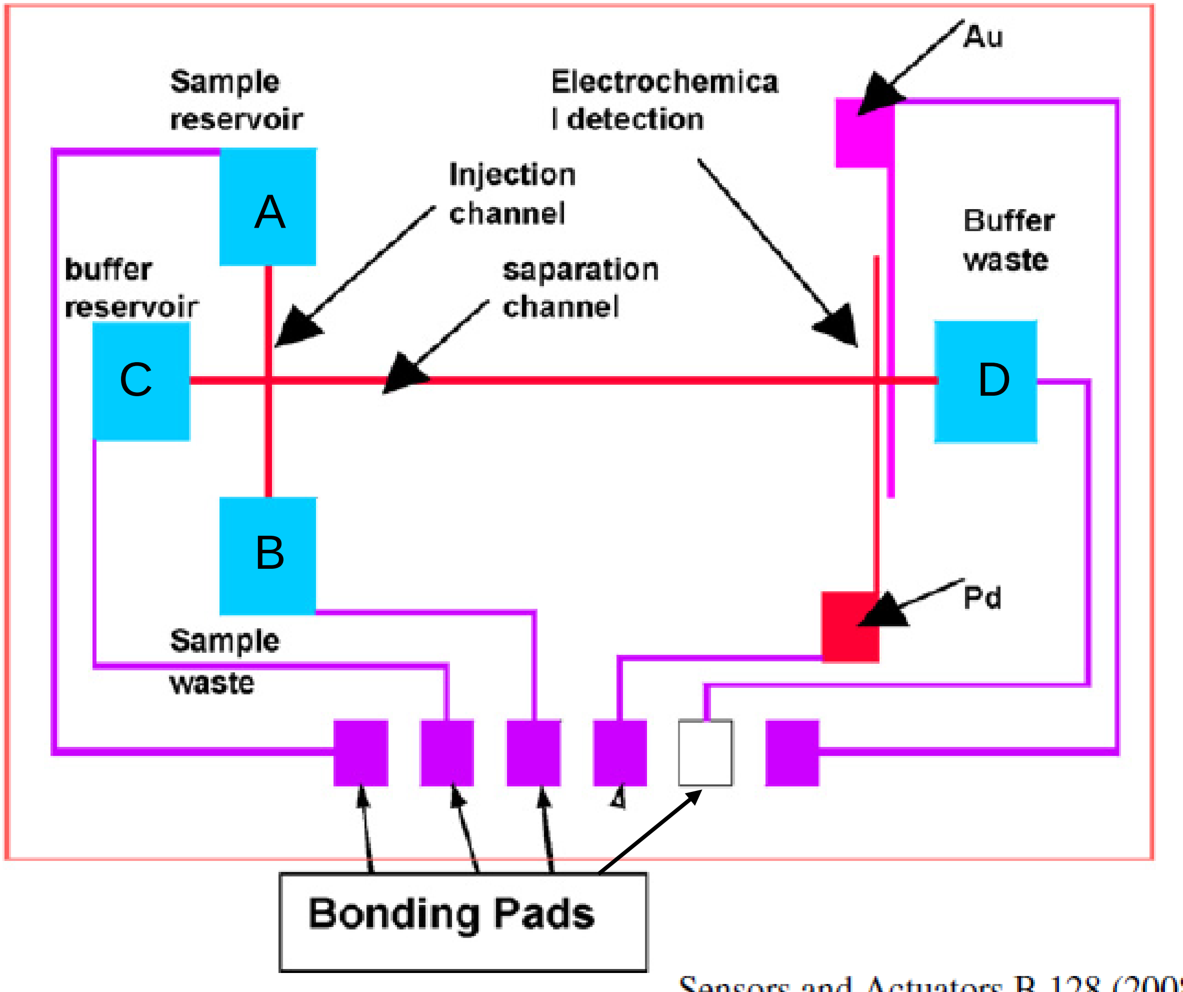


MEMS Handbook

Chip Example: Electrophoresis chip with electrochemical detection

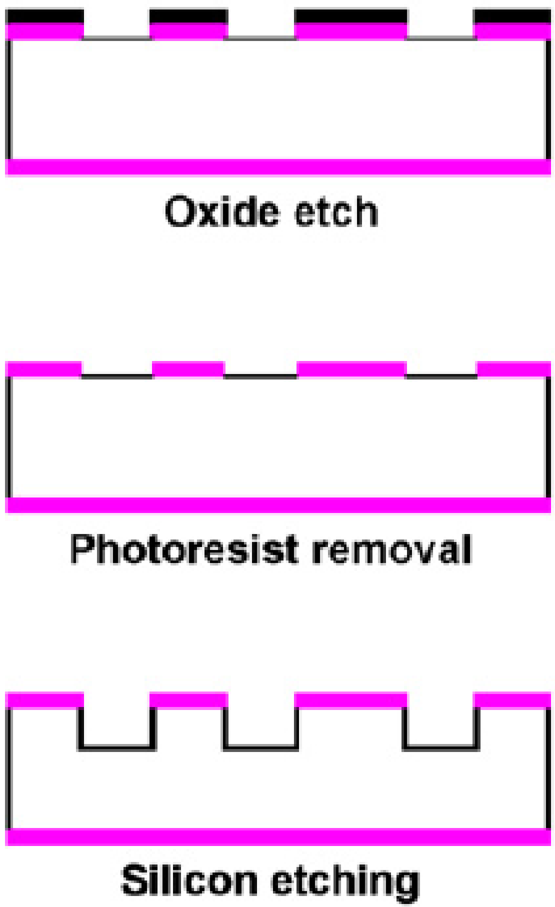
Injection: apply voltage to A and B.

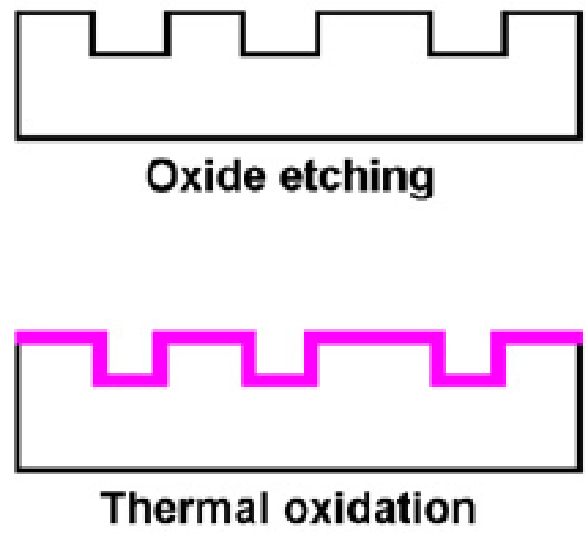
Separation: apply voltage to C and D.



Sensors and Actuators B 128 (2008) 422–426

CE chip fabrication (2): channels in silicon

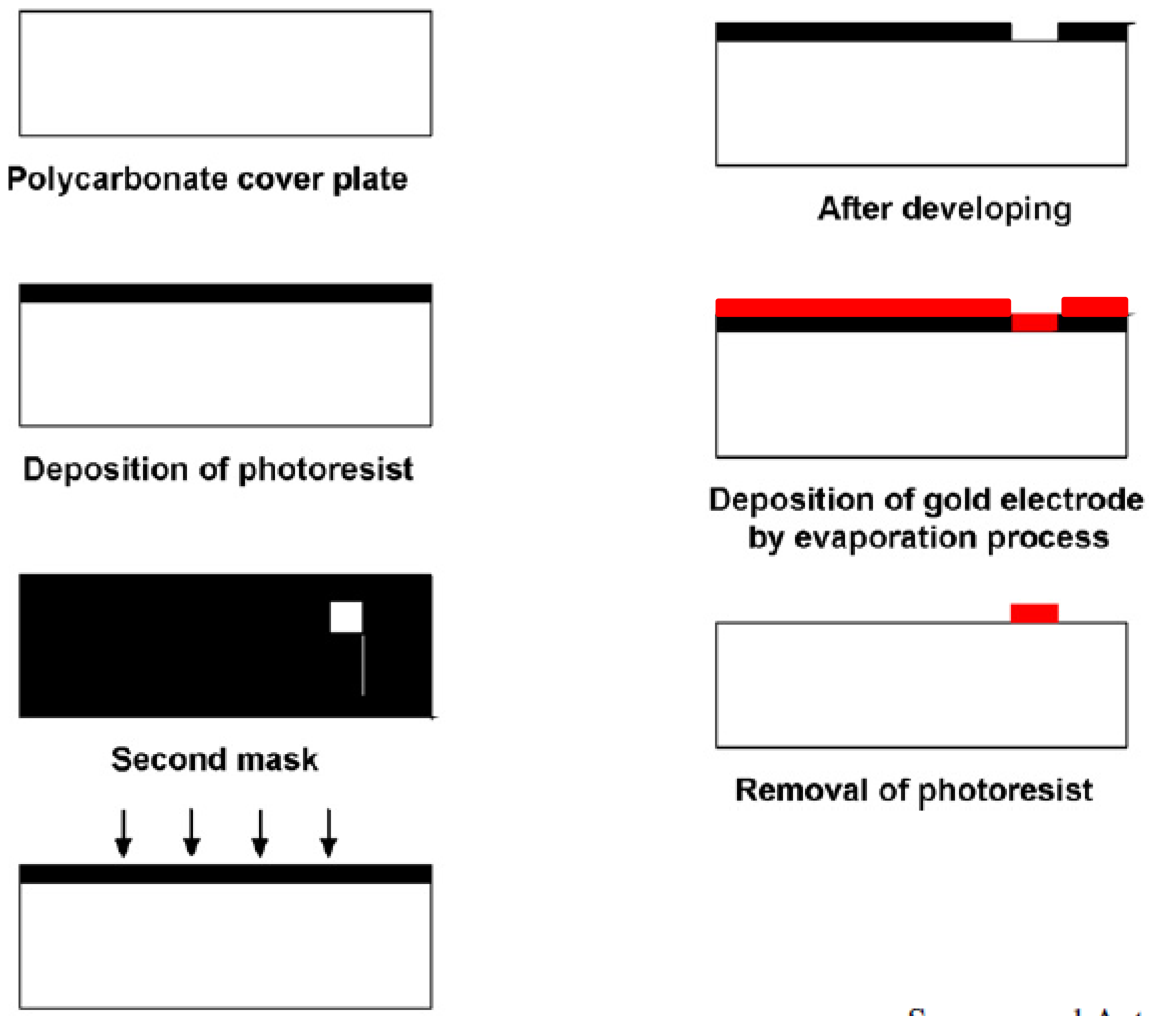




Because CE uses 500-1000 V, good electrical isolation needed ➔ SiO_2

Sensors and Actuators B 128 (2008) 422–426

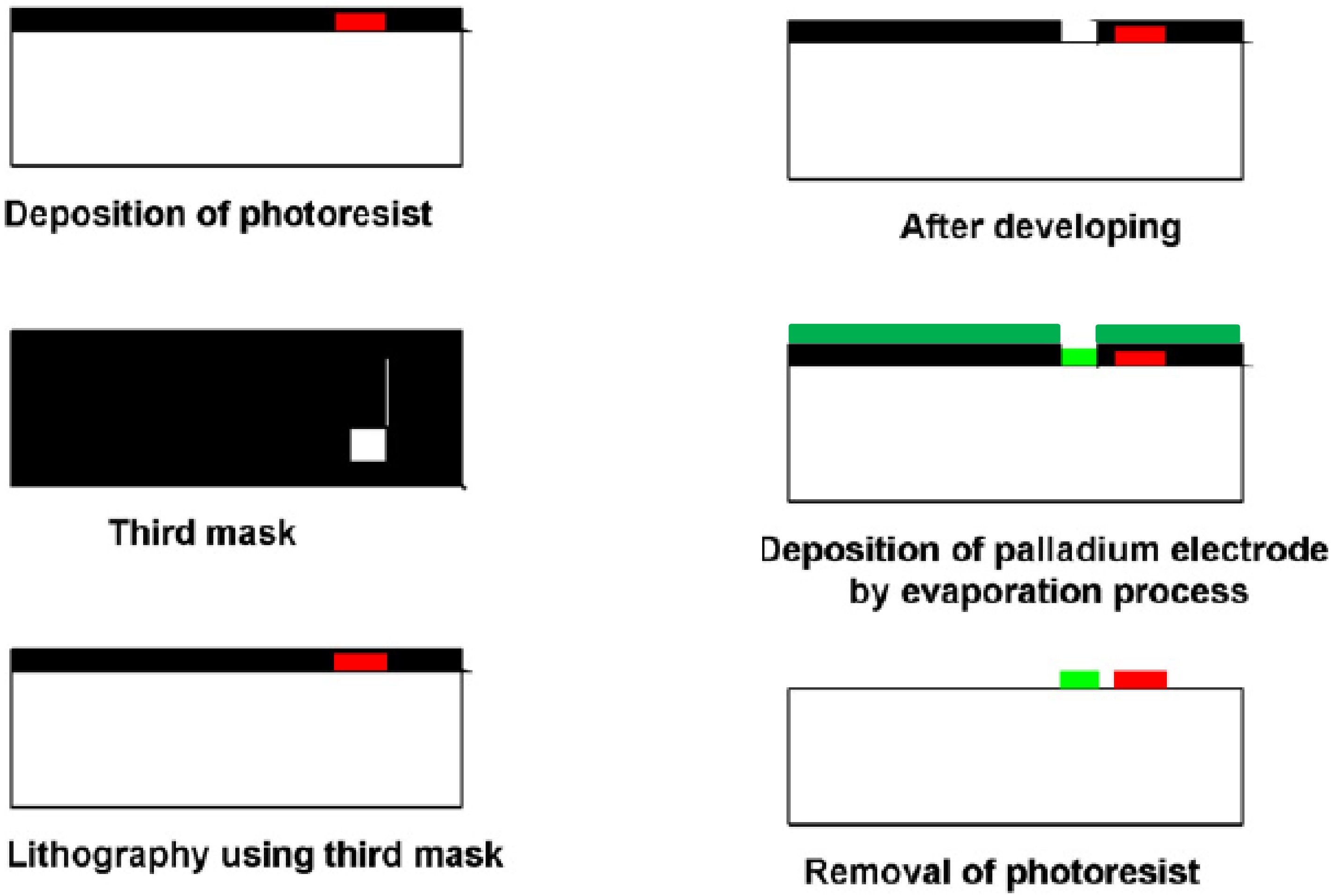
CE chip fabrication (3): Au-electrode on polycarbonate



Lift-off for metal patterning

Sensors and Actuators B 128 (2008) 422–426

CE chip fabrication (4): Pd-electrode on polycarbonate

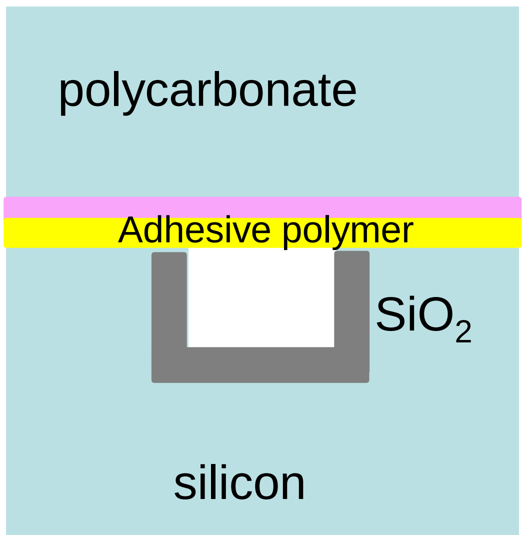


Lift-off

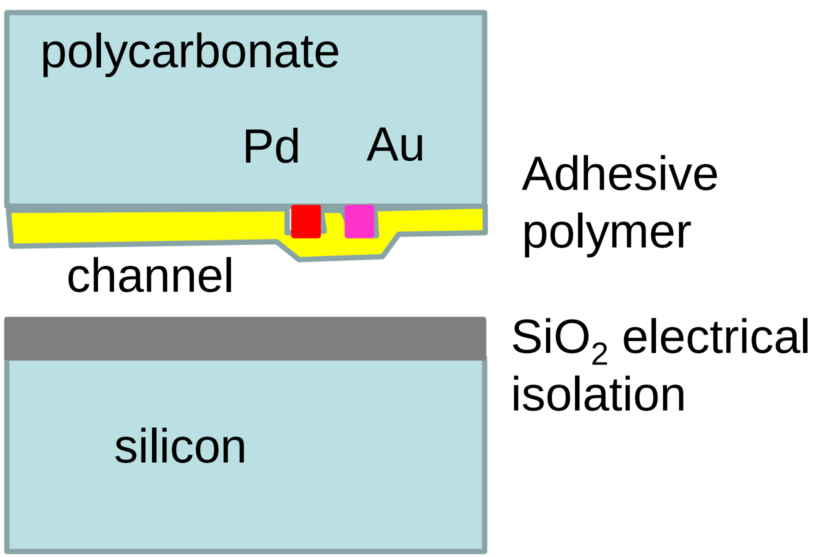
Sensors and Actuators B 128 (2008) 422–426

Adhesive bonding of Si and PC

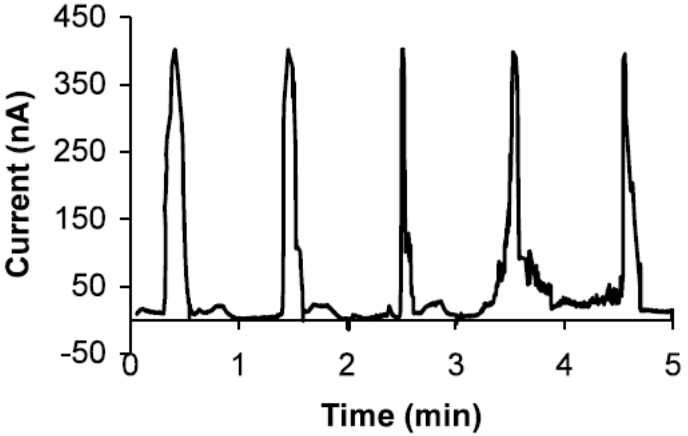
Cross section across the channel



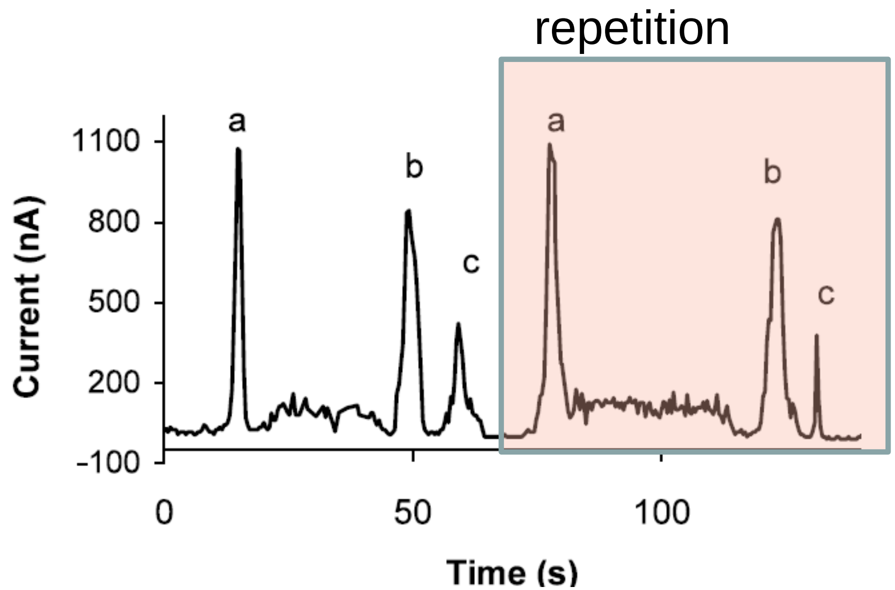
Cross-section along the channel



CE separations



Electropherogram for multiple injections of 10 mM hydrogen peroxide. Conditions: running buffer, phosphate buffer (10 mM, pH 7.4); separation potential, /400 V; injection potential, /400 V; detection potential, /700 mV



Electropherogram for sample solution containing 50 mM hydrogen peroxide (a), ascorbic acid (b) and uric acid (c), respectively. Conditions: two injections in the same run, other conditions were the same as those in Fig. 3.

Biosensors and Bioelectronics
Volume 19, Issue 3, 30 November 2003, Pages 149-153

Retraction

Sensors and Actuators B 128 (2008) 422–426

"The publisher regrets that the results presented in Figs. 6–8 are copied without permission or reference from an article that has already been published in Bios 19 (2003) 149–153 (DOI of the original article: doi:10.1016/S0956-5663(03)00178-7; PII of the original article: S0956-5663(03)00178-7)."

In reality, practically everything is copied from:

Ralph Wilke & Stephanus Büttgenbach:

A micromachined capillary electrophoresis chip with fully integrated electrodes for separation and electrochemical detection,

Biosensors and Bioelectronics, Volume 19, Issue 3, 2003, Pages 149-153

Original vs. copy

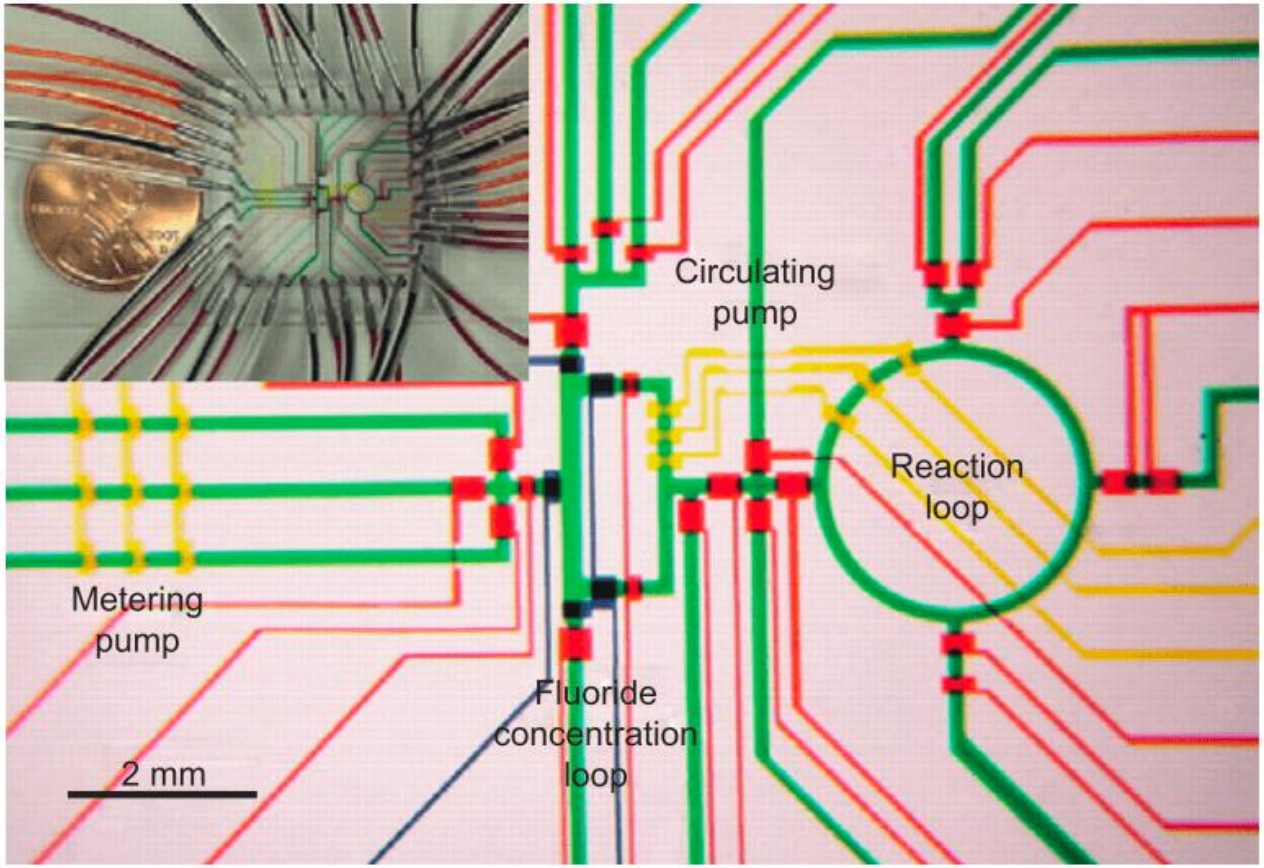
To overcome this difficulties we used a bonding procedure with an amorphous fluorocarbon polymer named CYTOP®. CYTOP® is a registered trademark of Asashi Glass Co. (Tokyo, JP) and was purchased from Sigma-Aldrich (Milwaukee, WI) as poly(1,1,2,4,4,5,5,6,7,7-decafluoro-3-oxa-1,6-heptadiene), silane modified, 9 wt.% solution in perfluorotributylamine. Both the cover plate and the microchannels were dehydrated at 90 °C for at least 30 min on a hotplate. The cover plate was cooled to room temperature and subsequently spin-coated with CYTOP®. During a softbake at 90 °C for 30 min the solvent was driven out. The two substrates were then aligned and bonded at 160 °C for at least 2 h with weights on top.

Ralph Wilke & Stephanus Büttgenbach

To overcome this difficulty we used a bonding procedure with an amorphous fluorocarbon polymer named CY-TOP®, CY-TOP® is a registered trademark of Asoshi Aldrich as poly(1,1,2,4,4,5,5,6,7,7-decafluoro-3-ora-1,6-heptadiene), silane modified, and 9 wt% solution in perfluorotributylamine. Both the cover plate and micro-channels were dehydrated at 90 ◦C for 30 min on the hot plate. The cover plate was cooled to room temperature and subsequently spin coated with CY-TOP®. During a soft bake at 90 ◦C for 30 min and the solvent was driven out. The substrates were then aligned and bonded at 160 ◦C for 2 h with weights on top.

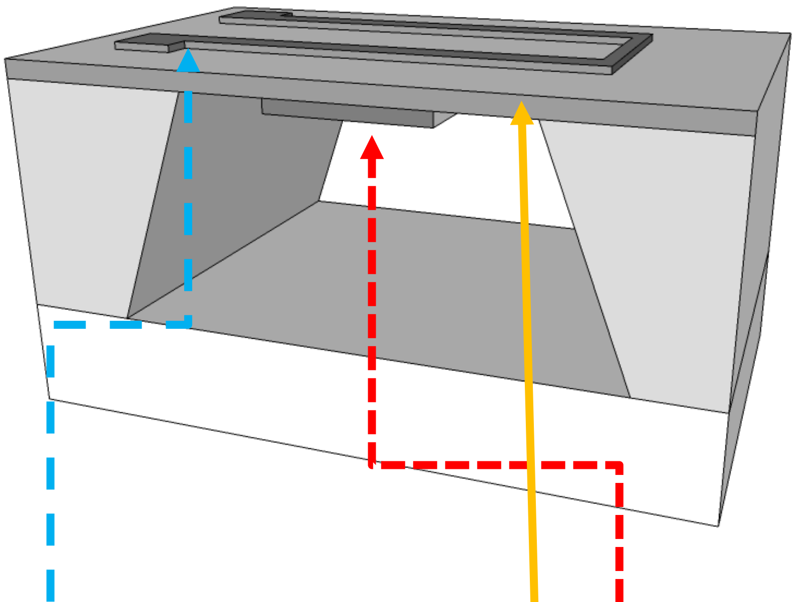
G.S. Virdi, R.K. Chutani, P.K. Rao, Sushil Kumar

Microreactors

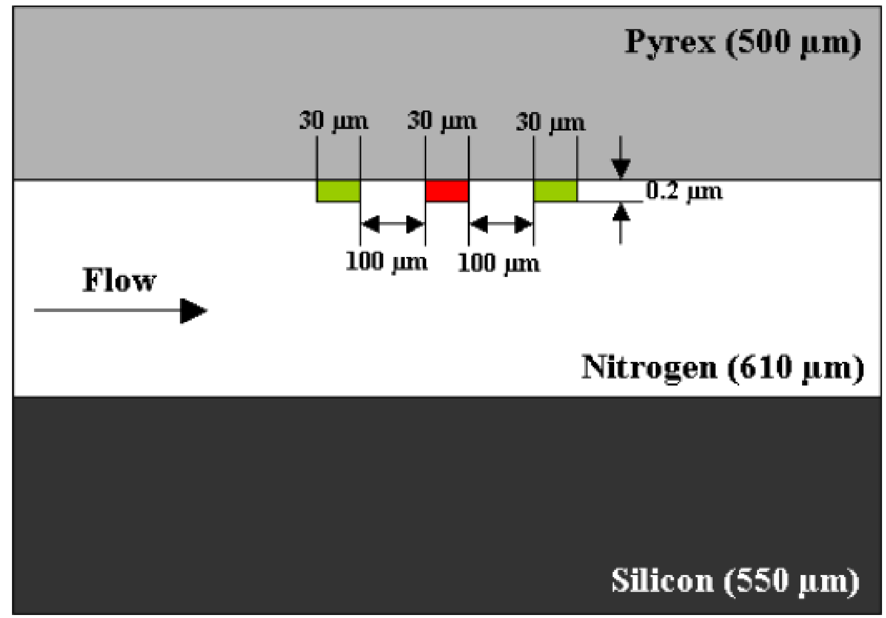


C.-C. Lee *et al.*, “Multistep synthesis of a radiolabeled imaging probe using integrated microfluidics.,” *Science*, 2005.

Simple microreactor

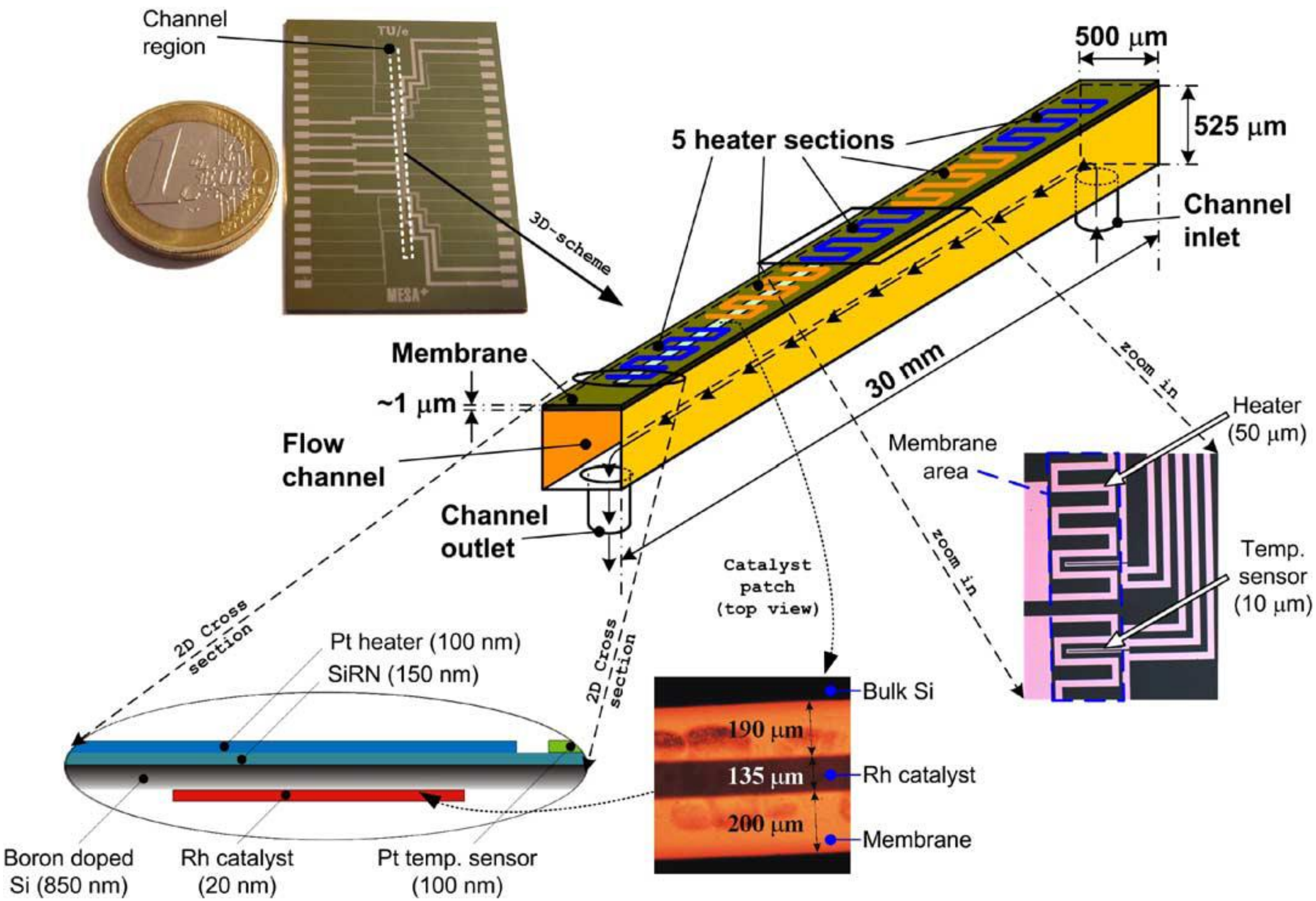


Heater electrode
Nitride membrane
Catalyst underneath
Flow channel
Bonded to glass wafer



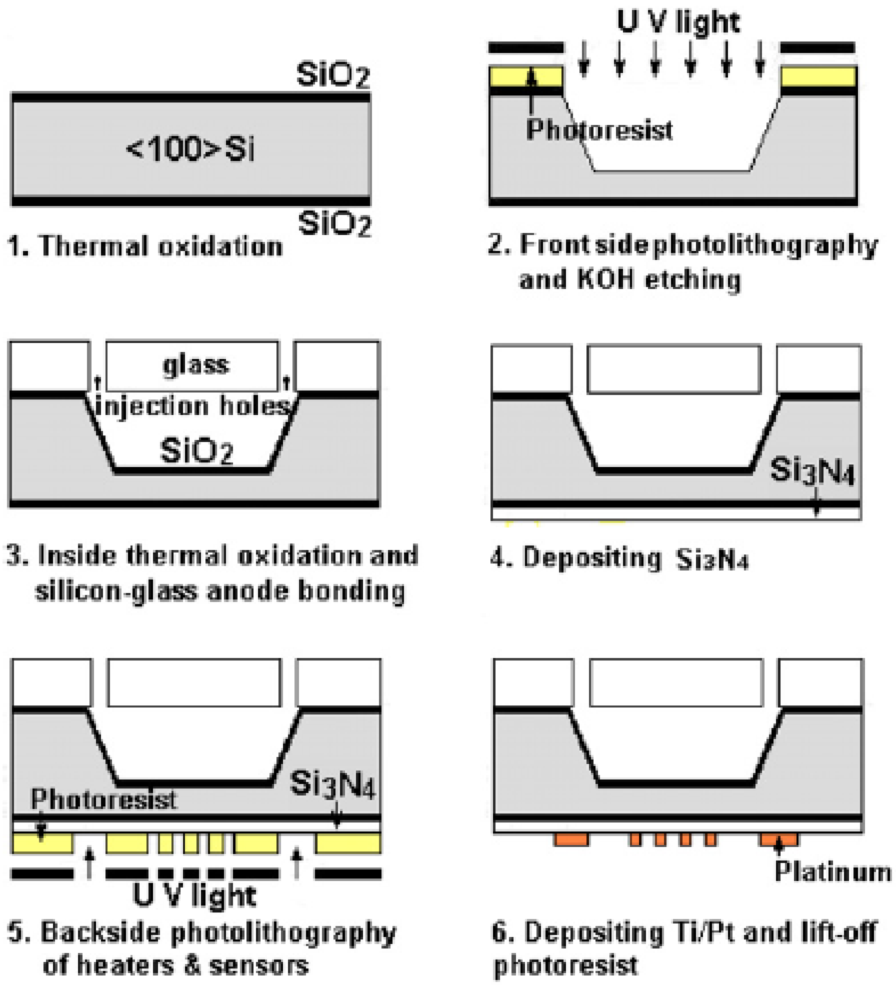
Microreactor dimensions
Shin & Besser,
J. Micromech. Microeng. **16** (2006) 731–741

Linear microreactor



R.M. Tiggelaar et al. / Sensors and Actuators A 119 (2005) 196–205

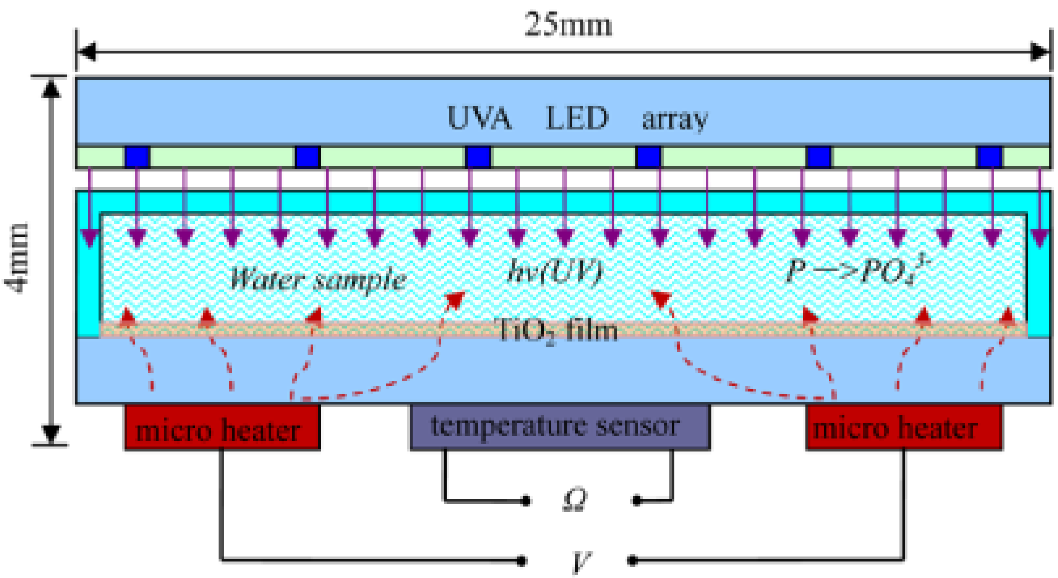
Microreactor with platinum heaters and glass cover



Transparent glass for detection; silicon spreads heat well for temperature uniformity

J. Micromech. Microeng. 15 (2005) 1476–1481

TiO_2 photocatalytic reactor



"Thermally assisted photocatalytic microfluidic chip and its application to the digestion of total phosphorus (TP) in freshwater"

Heating only locally ➔ power consumption reduced.

UV activation ➔ lower temperature suffices.

TiO_2 photocatalytic ➔ no oxidant consumption

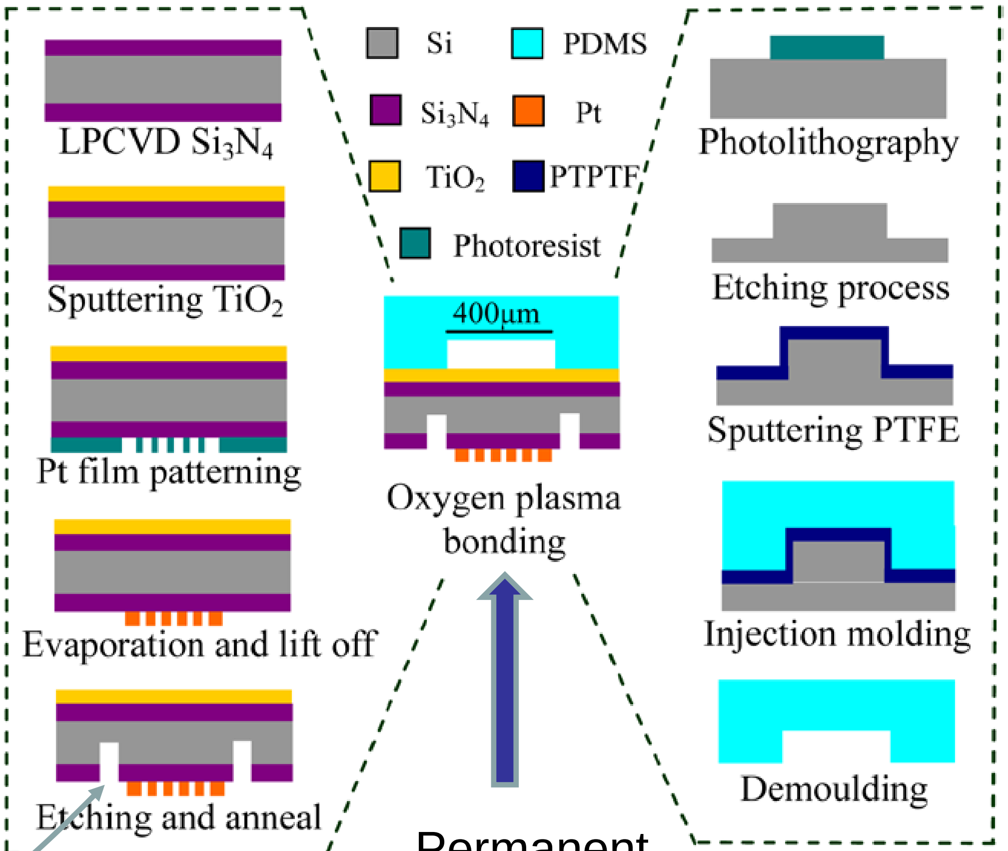
Integrated electrodes can monitor phosphorous removal.

Tong et al: J. Micromech. Microeng. 25 (2015) 025006

TiO_2 reactor fabrication

Silicon part contains the thin films (TiO2 and Pt heater electrode).

Grooves etched into silicon act as thermal isolation.



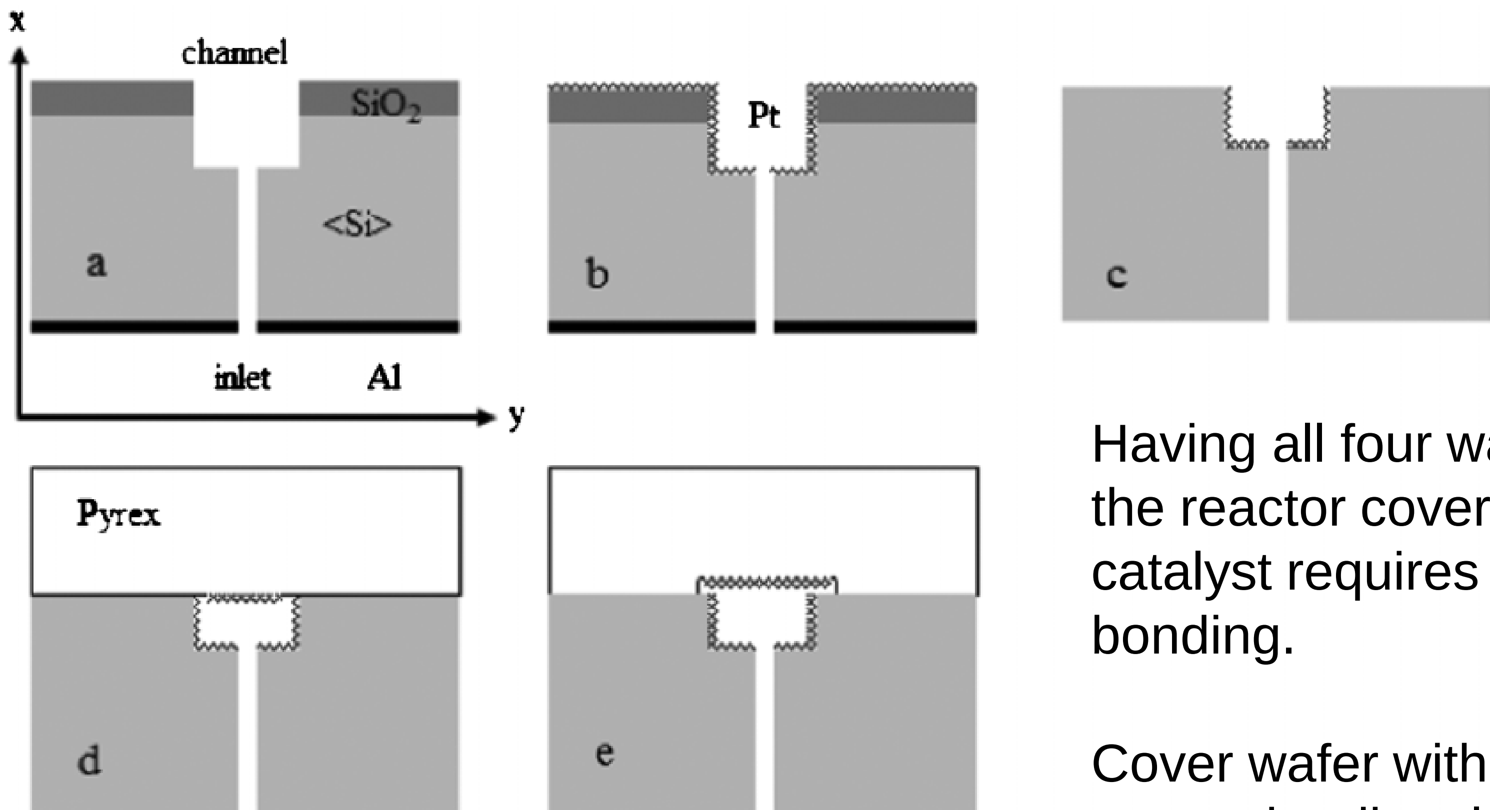
Permanent bonding by plasma treatment

PTFE (Teflon) acts as an anti-adhesive layer, making release from mould easier.

PDMS transparency in UV is essential.

Tong et al: J. Micromech. Microeng. 25 (2015) 025006

Catalytic microreactor

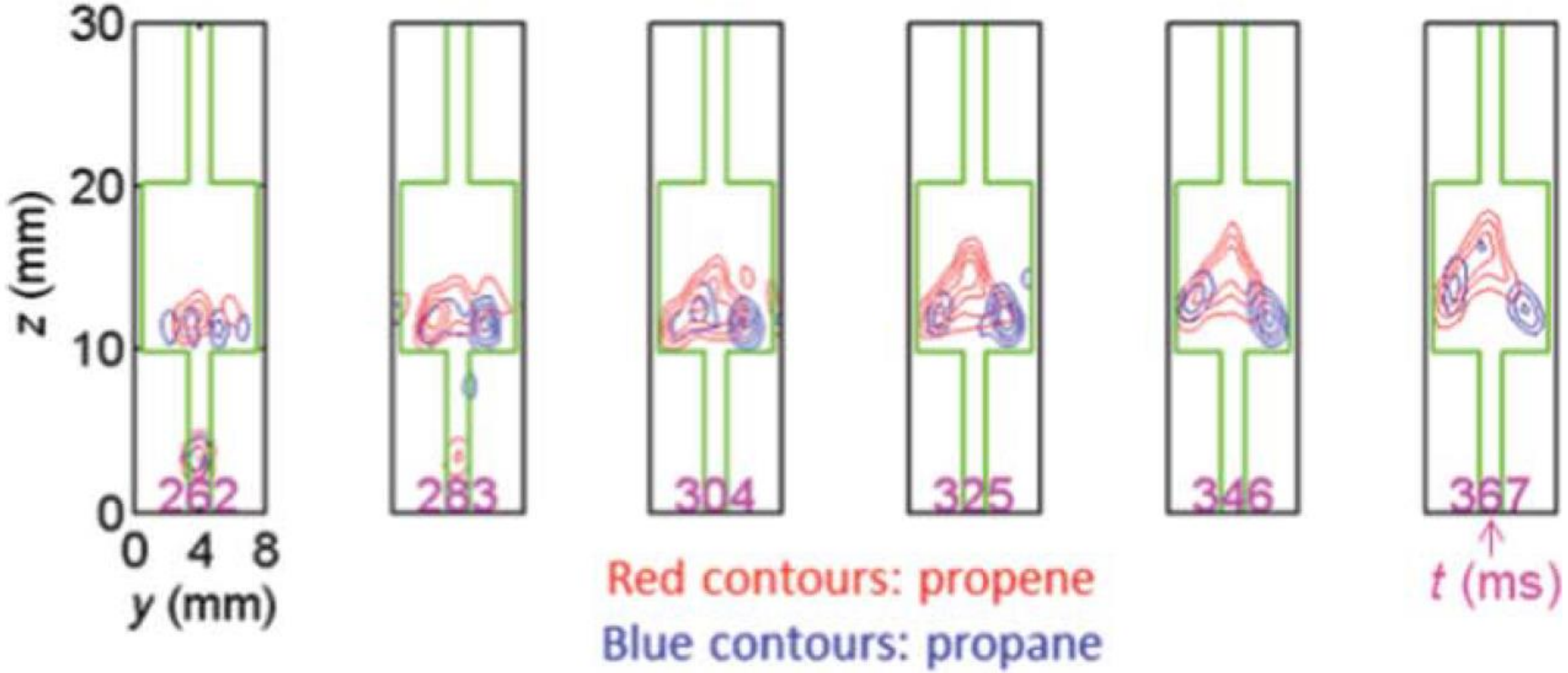


Having all four walls of the reactor covered by a catalyst requires aligned bonding.

Cover wafer with catalyst cannot be directly bonded, because it is not smooth.

Zhivonitko, Telkki, Scotti, Franssila, Koptyug: DOI: 10.1039/c3lc41309h

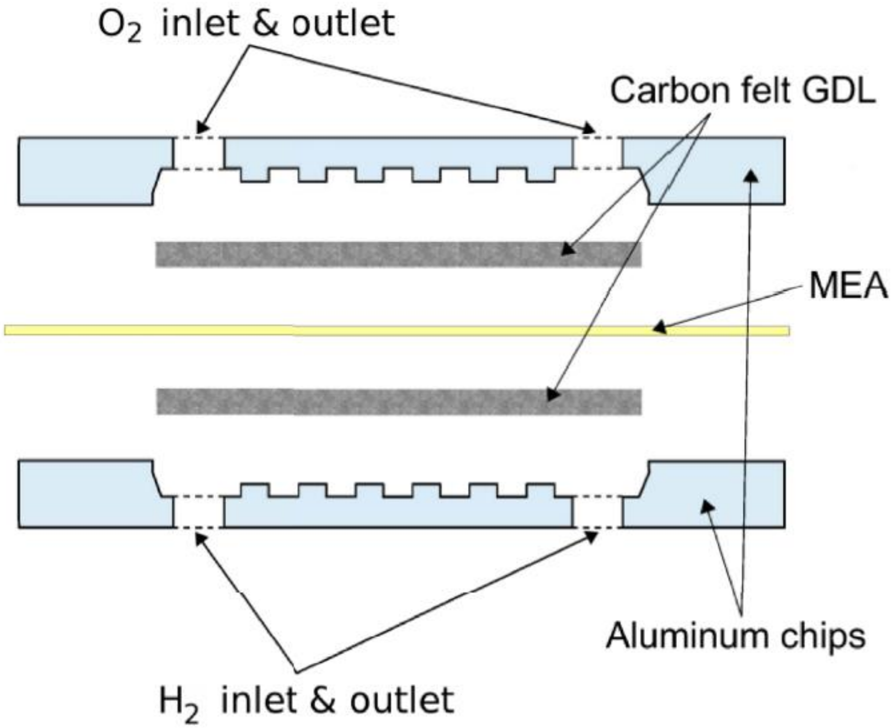
Hydrogenation of propene into propane

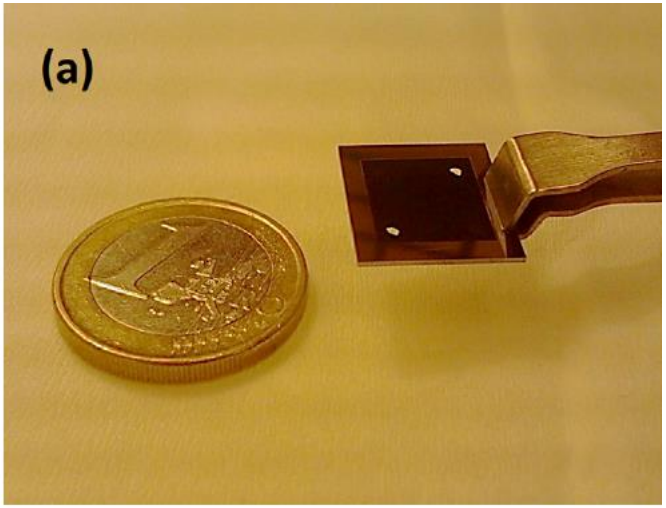


Flow patterns detected by NMR with 10 ms time resolution.

Zhivonitko, Telkki, Scotti, Franssila, Koptyug: DOI: 10.1039/c3lc41309h

Micro fuel cell



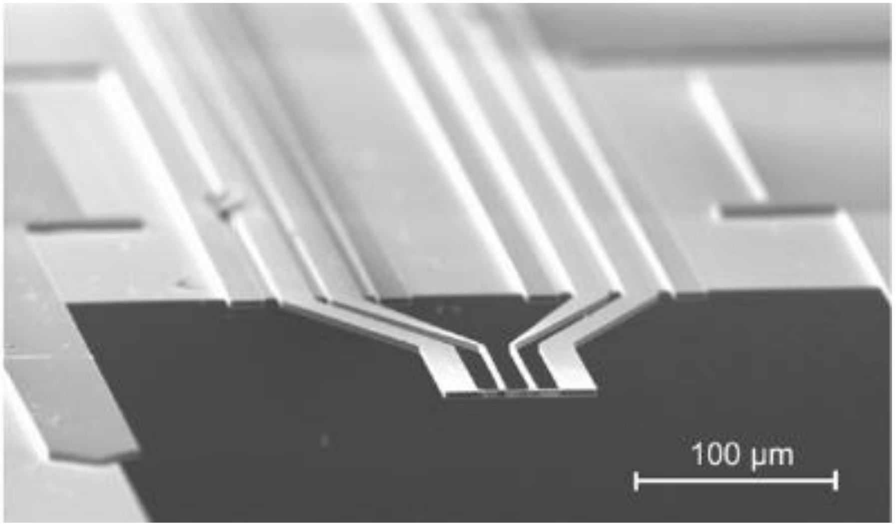


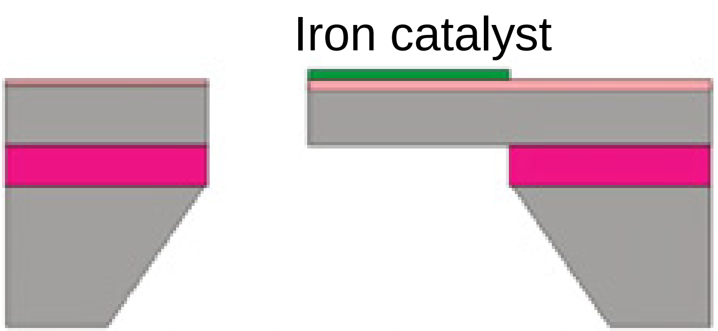
Anode and cathode are microfabricated,
But many manual assembly steps are needed
to put together a functioning fuel cell.

Scotti, Franssila… JMEMS 2014

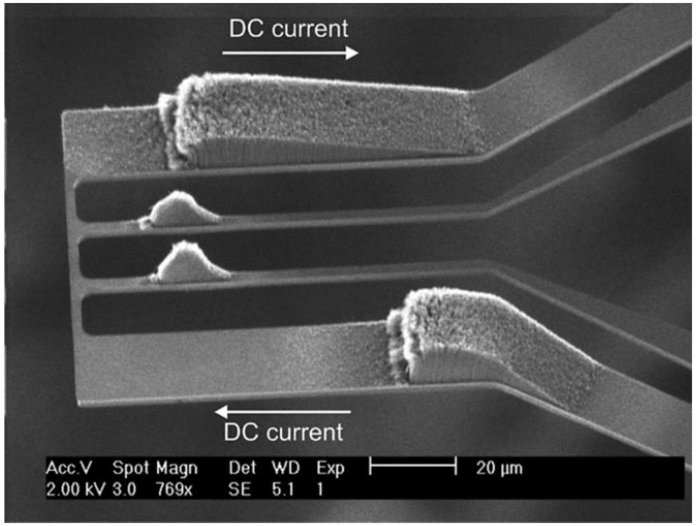
Borghei, Franssila et al: Energy
65 (2014) 612e620

A microreaction spot





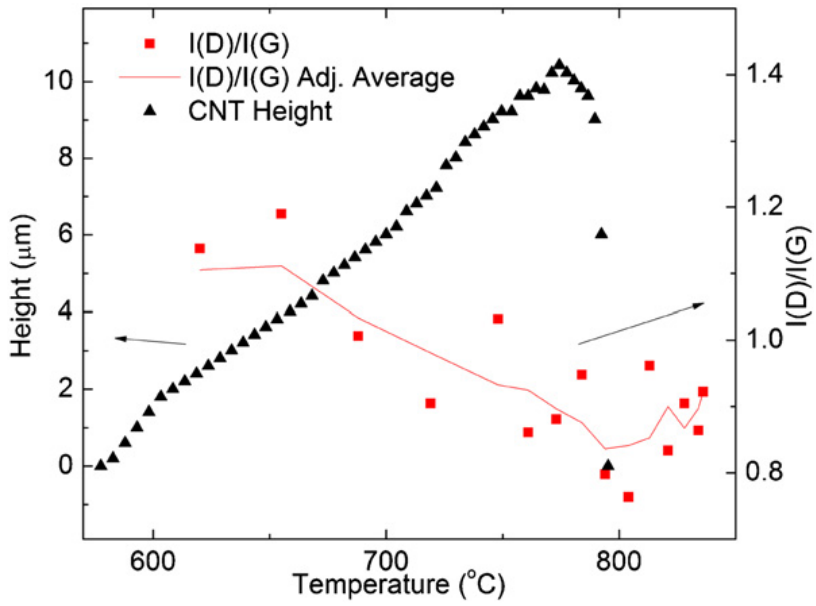
Locally heating the reaction spot only, in this case to high temperature of ca. 800ºC for CNT synthesis.

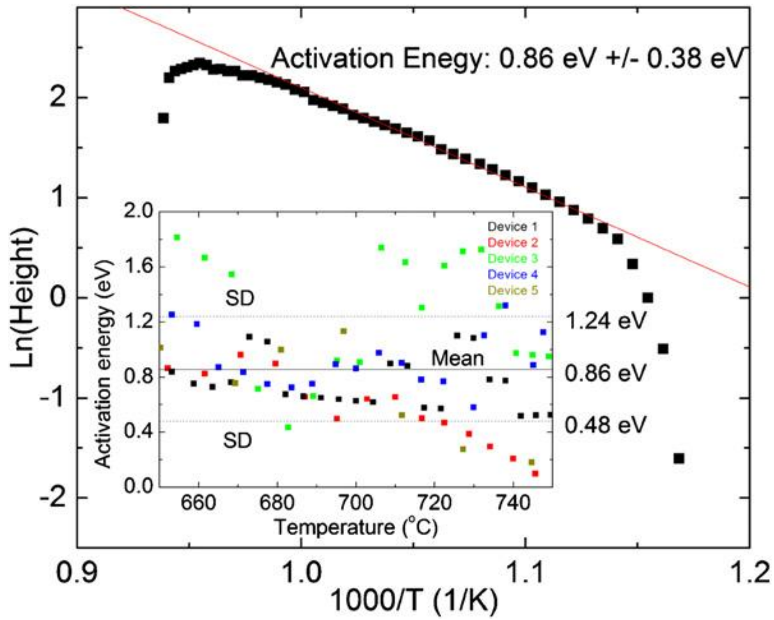


Daniel S Engstrøm[1], **Nalin L Rupesinghe**[2], **Kenneth B K Teo**[2], **William I Milne**[3] **and Peter Bøgild**[1]

J.Micromech.Microeng. 2011

CNT results





CNT height as a function of growth temperature.

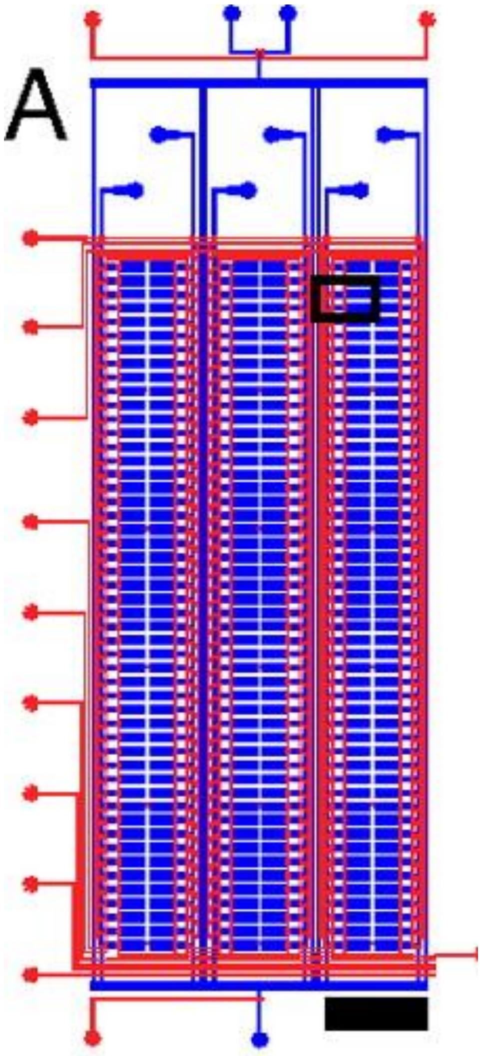
Raman of I_D/I_G ratio

Activation energy of CNT growth

Daniel S Engstrøm[1], Nalin L Rupesinghe[2], Kenneth B K Teo[2], William I Milne[3] and Peter Bøgild[1]

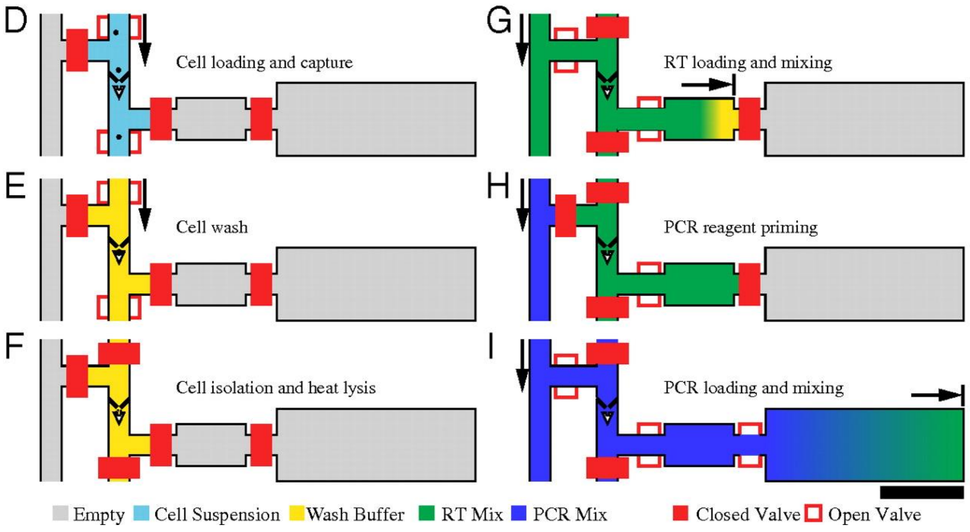
J.Micromech.Microeng. 2011

Combining reactors with valves



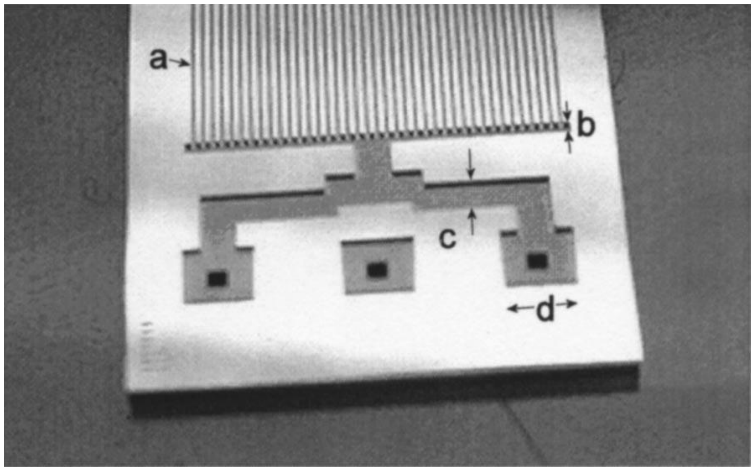
Six independent sample-loading lanes, each containing 50 cell-processing units ➔ 300 parallel PCR reactions. 1,000 measurements on a device with an area of one square inch.

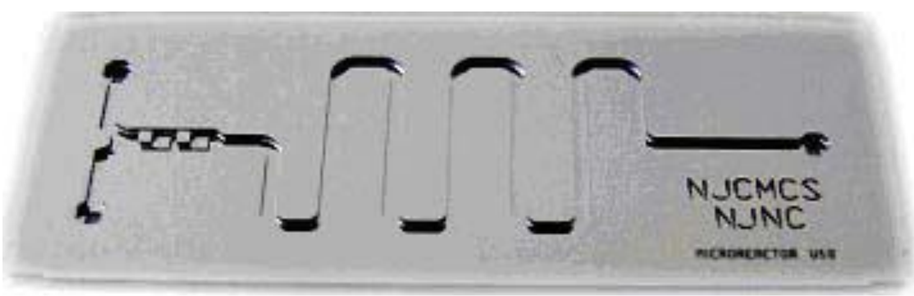
(*D*) A single-cell suspension is injected into the device. (*E*) Cell traps isolate single cells from the fluid stream and permit washing of cells to remove extracellular RNA. (*F*) Actuation of pneumatic valves results in single-cell isolation prior to heat lysis. (*G*) Injection of reagent (green) for RT reaction (10 nL). (*H*) Reagent injection line is flushed with subsequent reagent (blue) for PCR. (*I*) Reagent for qPCR (blue) is combined with RT product in 50 nL qPCR chamber.



Adam White et al: PNAS August 23, 2011 108 (34) 13999

Microreactor pros and cons





Small volume good if expensive and/or dangerous chemicals

Fast reactions because small diffusion distances

Large surface area (either positive or negative effect)

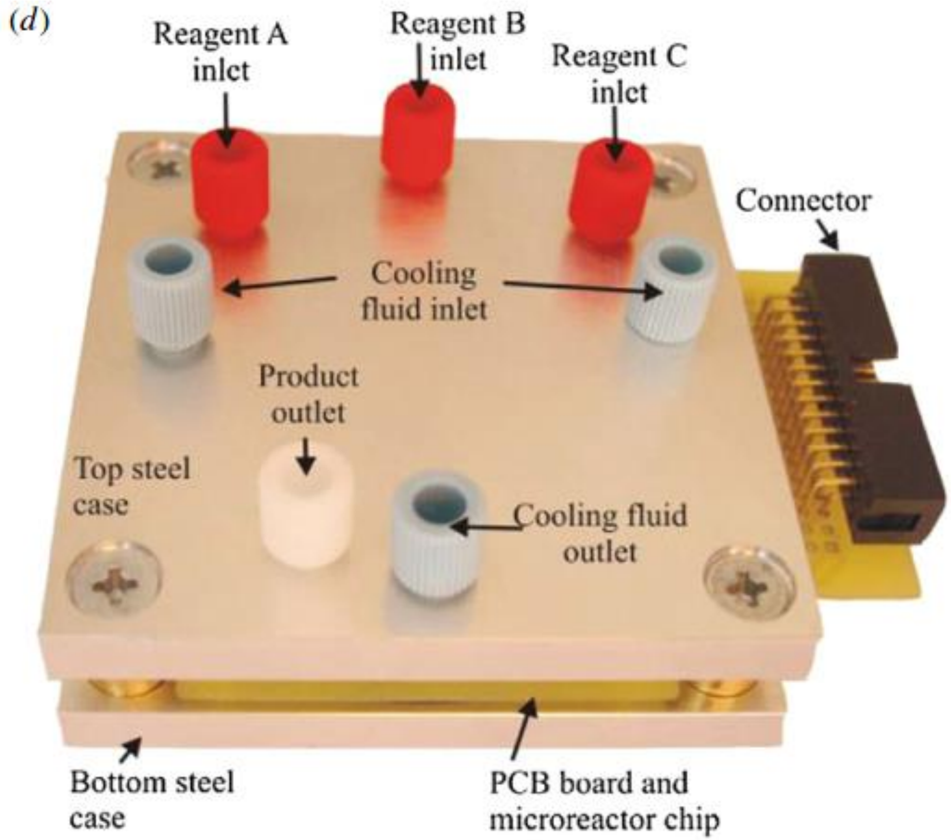
Good temperature control and fast ramp rates

Good flow control because of laminar flow

Besser: J. Vac. Sci. Technol. B 21.2., Mar/Apr 2003

Shin & Besser, JMM 16 (2006) p. 731

Reactor packaging



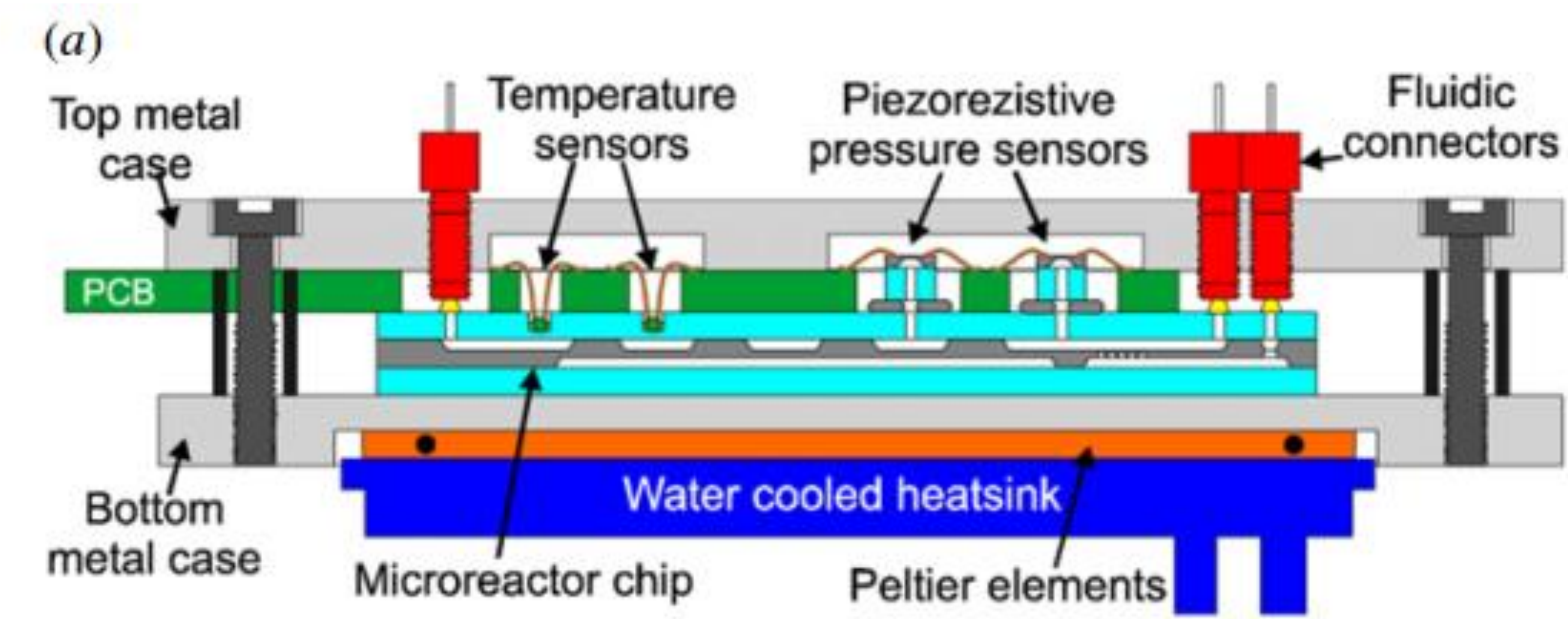
Fluidic inlets/outlets for reactants, products, waste

Fluidic inlets for cooling fluids, broth, oxygen

Electrical connections to driving electrodes and detector electrodes

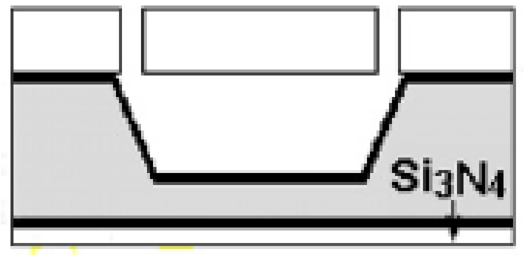
J. Micromech. Microeng. 23 (2013) 035014

The complete system

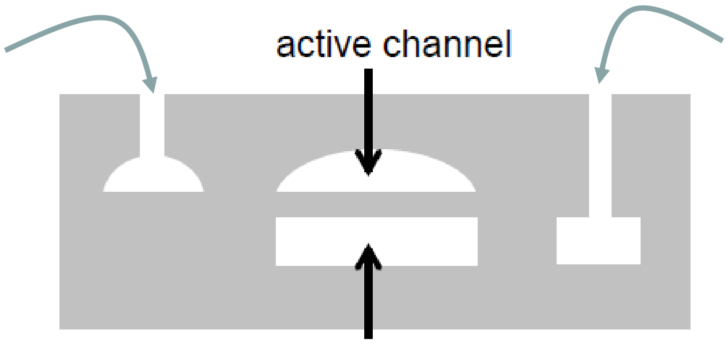


J. Micromech. Microeng. 23 (2013) 035014

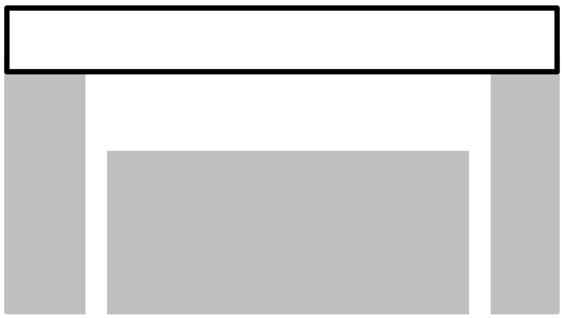
Inlet/outlet holes



Sandblasting in glass



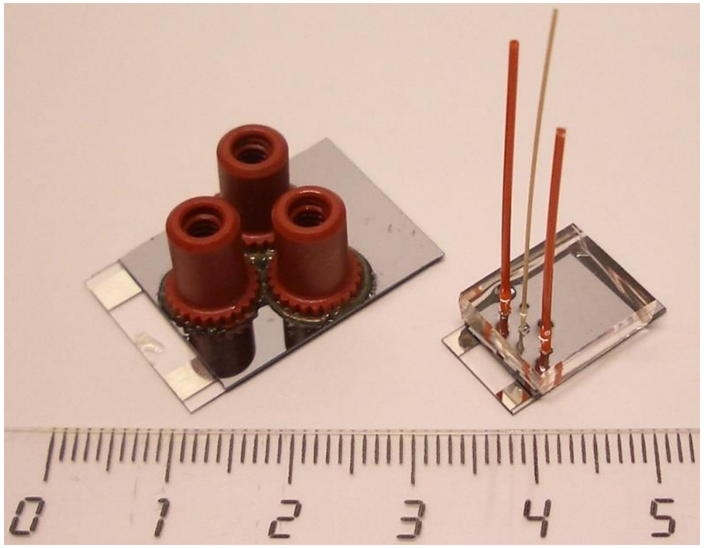
Punching in PDMS



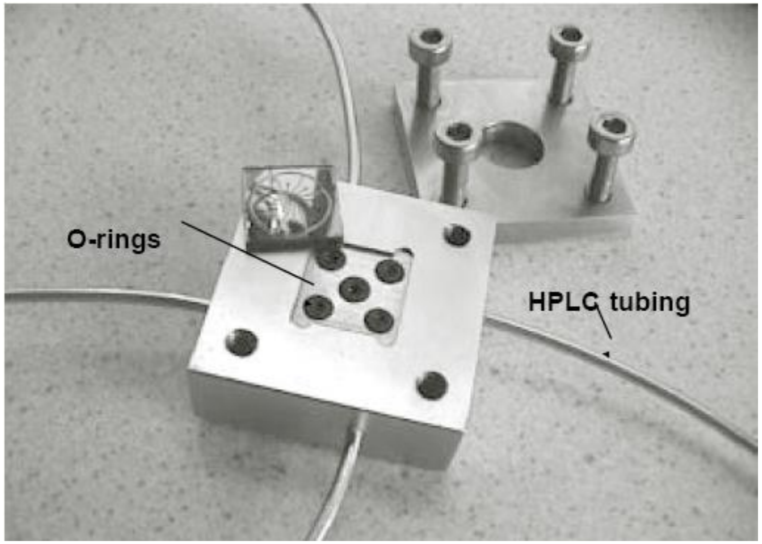
DRIE/plasma
etching in silicon

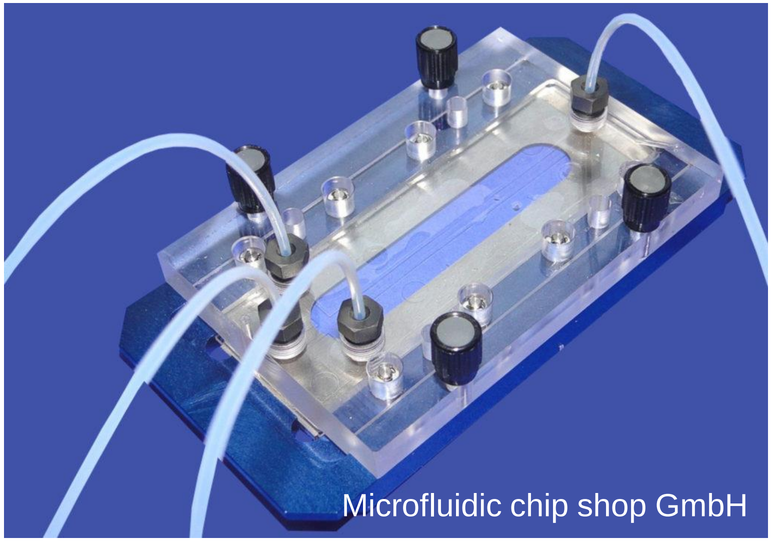
Drilling in copper

Fluidic connectors



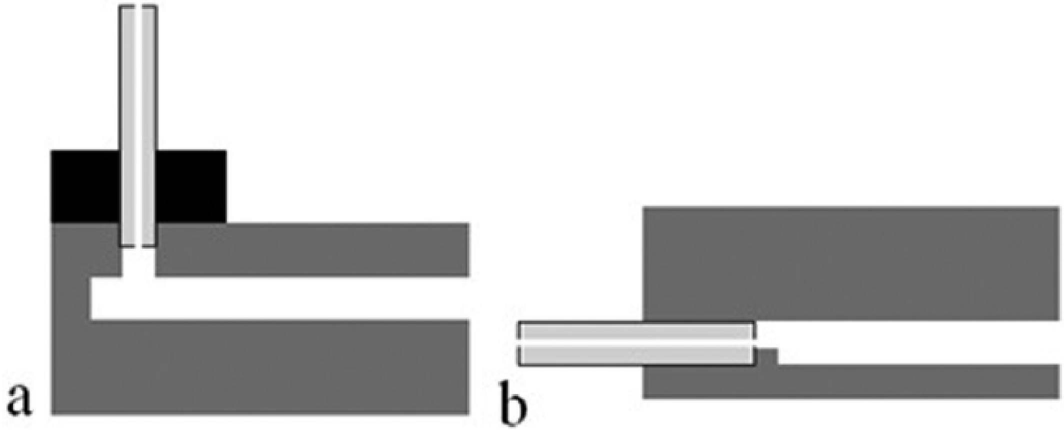
Ville Saarela, TKK

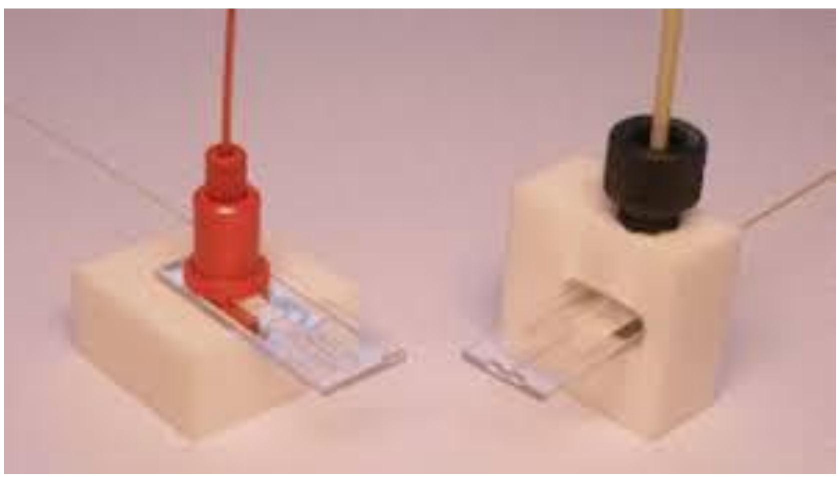




Micro-macro conversion is often difficult, because of size differences ➔ dead volume issues

In-plane vs, out-of-plane





Liquid connection is from the side; and gas connection from top.

Iliescu, Taylor, Avram, Miao, Franssila: Biomicrofluidics 6, 016505 (2012);

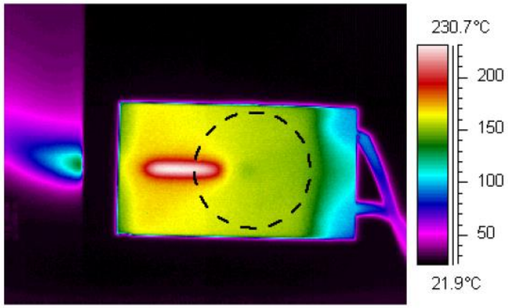
Interconnect consideration

- Is the microfluidic device re-usable or disposable?

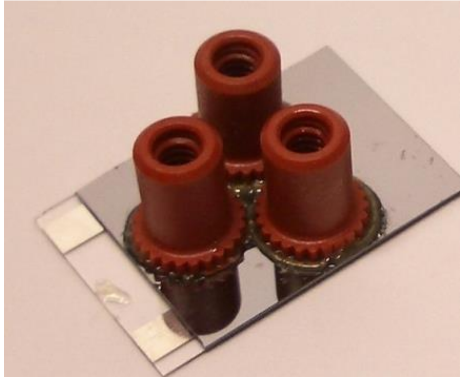
In other words: how frequently do world-to-chip connections need to be broken and re-made?

- the amount of chip area used by the interconnections
- pressure tolerance
- temperature tolerance
- automation vs. manual labor
- price

Ville Saarela, Aalto

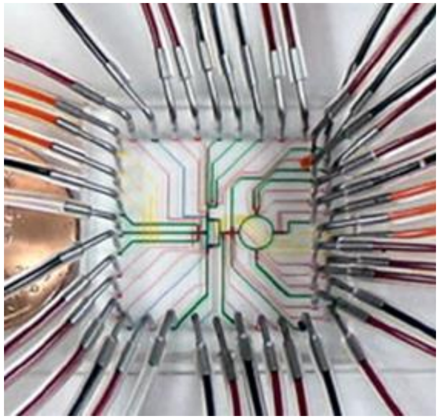


Chip running so hot that gluing is not an option



Ville Saarela, Aalto

Very large area taken up by connectors



Cumbersome manual connections

https://sites.google.com/site/vandamlab/research/microfluidic-interfaces

Take home messages

Integrated systems are often desired, but difficult.

Silicon and glass for high-T and high pressure systems.

Some of the components remain macroscopic, e.g. pump or detector.

Integrated valves enable systems that start to resemble microelectronic circuits.

Microreactors benefit from miniaturization in multiple ways.

Interconnects often non-micromachined, and cumbersome.