The Abdus Salam
International Centre for Theoretical Physics

United Nations
Educational, Scientific
and Cultural Organization

International Atomic
Energy Agency

SMR.1670 - 14

INTRODUCTION TO MICROFLUIDICS

8 - 26 August 2005

Liquid Processing Microcomponents and Devices

R. Luttge
University of Twente, Enschede, The Netherlands

Topics in this lecture

Small volume liquid processing
Components and devices units: principles, designs, and fabrication.

From μTAS to Lab-on-a-Chip
Overview to research and developments of dispensers, which are considered as the "heart" of new microfluidic platform developments, e.g., in (bio) chemical screening experiments.

Applications
Examples related to specific technical problems also somewhat more exotic components are presented that are designed by the knowledge of specific physical/chemical effects, e.g., hydrophobicity.

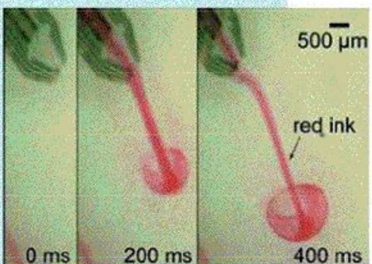
3. Liquid processing microcomponents and devices

- Introduction
- Structural elements and integration: developments of microfluidic components
  - Device versus component
  - Valves, pumps, mixers, flow sensors
- Examples of microfluidic "platforms"
  - Dispensers
  - Particle handling
- Outlook: Future developments
- Summary

Topics in this section

Fluidics goes small

Components for platforms



Parylene probe, S. Takeuchi et al., Lab Chip, 2005, 5, 519–523

Introduction

- Smaller must be also better!
  - Manufacture length scale.
  - High-throughput screening due to large-scale integration.
  - Devices for research to understand phenomena in high-risk applications (chemistry, toxicology, high electrical field, high pressure etc.).

http://www.tecan.co.uk/

Smaller = better and cheaper?

From production point of view

- Only if there are many to make, otherwise to extensive in development time and cost.

From application point of view:

- Needs to fulfill a specific functionality when integration at high costs is pursued.
- Miniaturization often has drawbacks, too. These have to be either compensated by design or a functional sacrifice is cost-driven!

We will further discuss these aspects in the last lecture of this week: *Design Issues.*

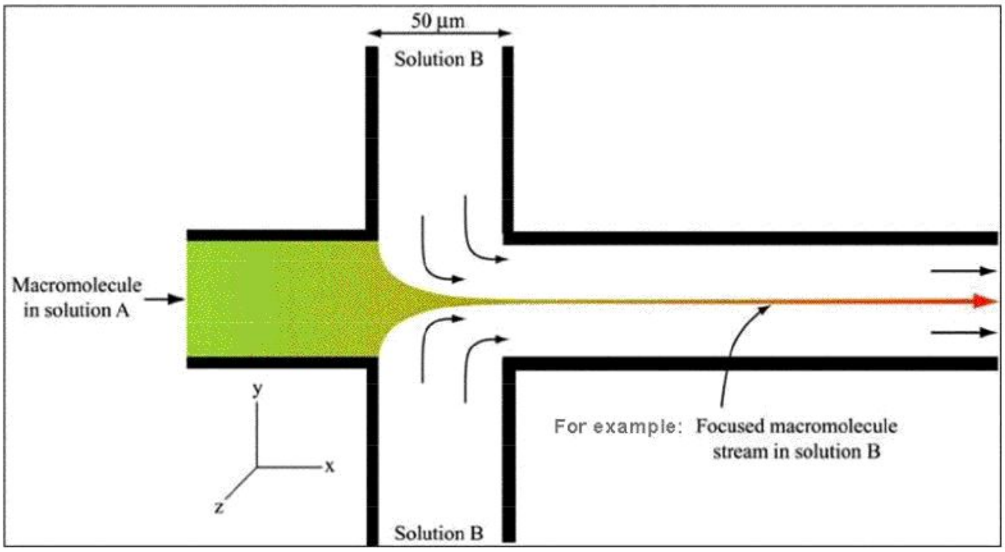
Length scale of manufacture

- Laminar flow: minimal convection.
- Enhance the net diffusion rate by increasing the interface area between the two fluid streams.
- Fast response of sensor elements due to minimized diffusion length.

Guided fluid flow

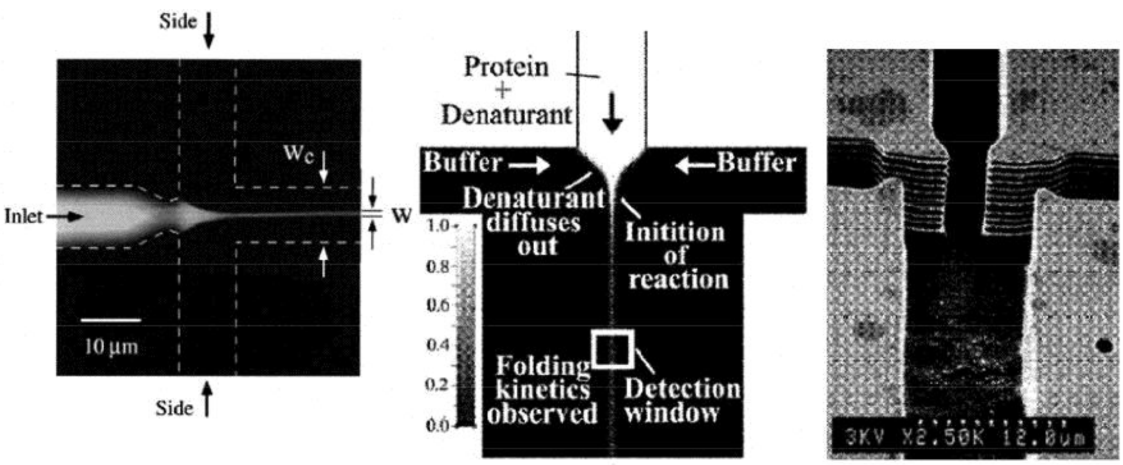
Control of fluid flow width

- Channel dimensions result in laminar flow profiles



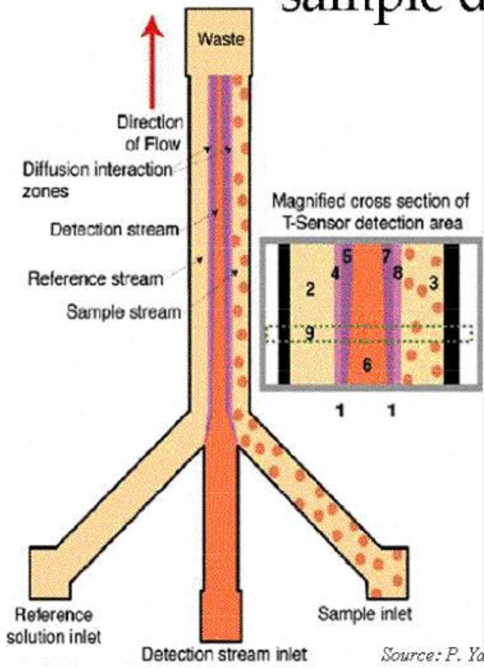
Laminar flow application

Protein folding kinetics



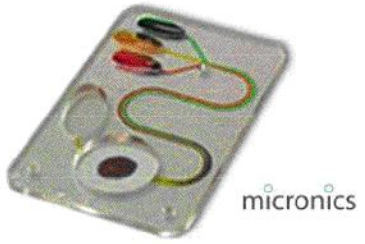
J.B. Knight, et al. / Phys. Rev. Lett. 80, 1998, 3863-3866
D.E. Hertzog, et al. / Proc. Micro Total Analysis Systems Conf. 2003, Squaw Valley, Oct. 5-9, 2003, pp. 891-894

On-line laminar flow sample derivatization and detection



Source: P. Yager, Univ. of Washington, USA

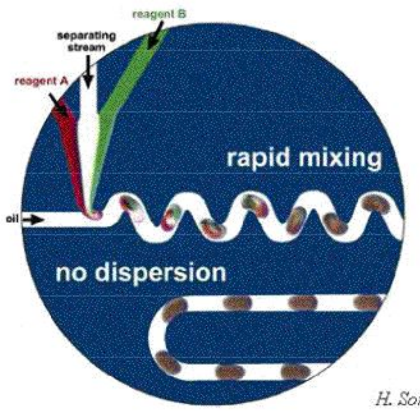
- Reference and sample solution are brought into contact with a detection solution downstream.
- Reactions occur on-line in the interdiffusion (mixed) zones.

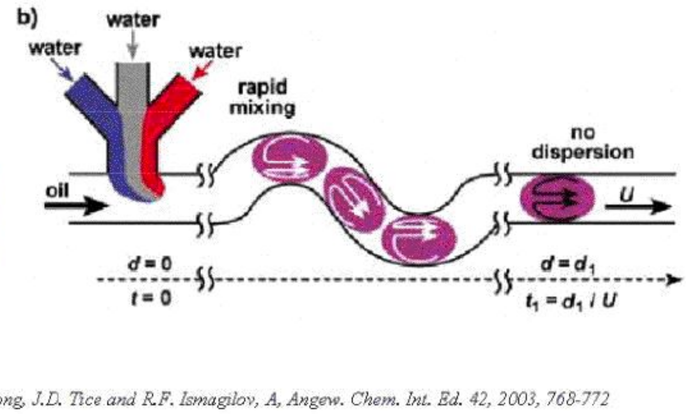


Time-periodic re-circulating

Spatial confinement-assisted reaction kinetics

- Microfluidic network for controlling reaction in time.
- Recirculation caused by the shearing interaction with the walls.

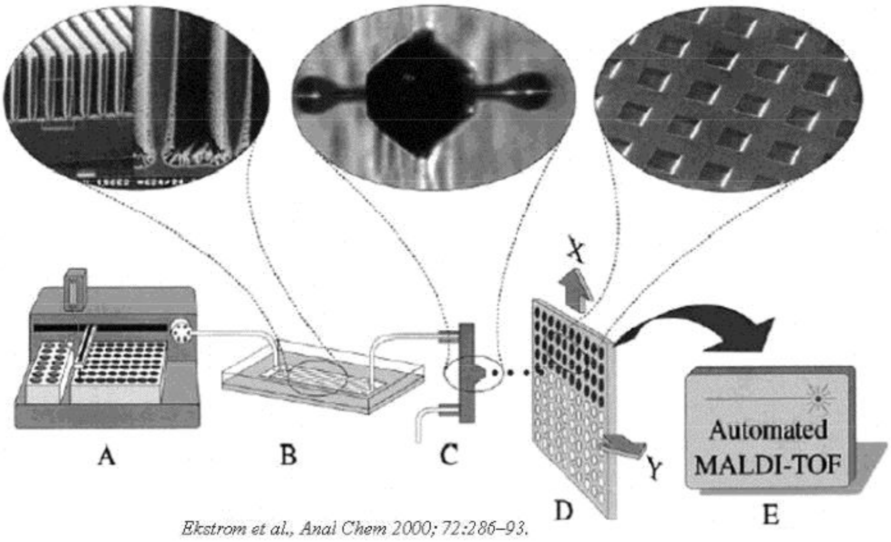




H. Song, J.D. Tice and R.F. Ismagilov, A, Angew. Chem. Int. Ed. 42, 2003, 768-772

Components in a hybrid platform = advanced systems for high-throughput!

Microdigestion of proteins (MS)

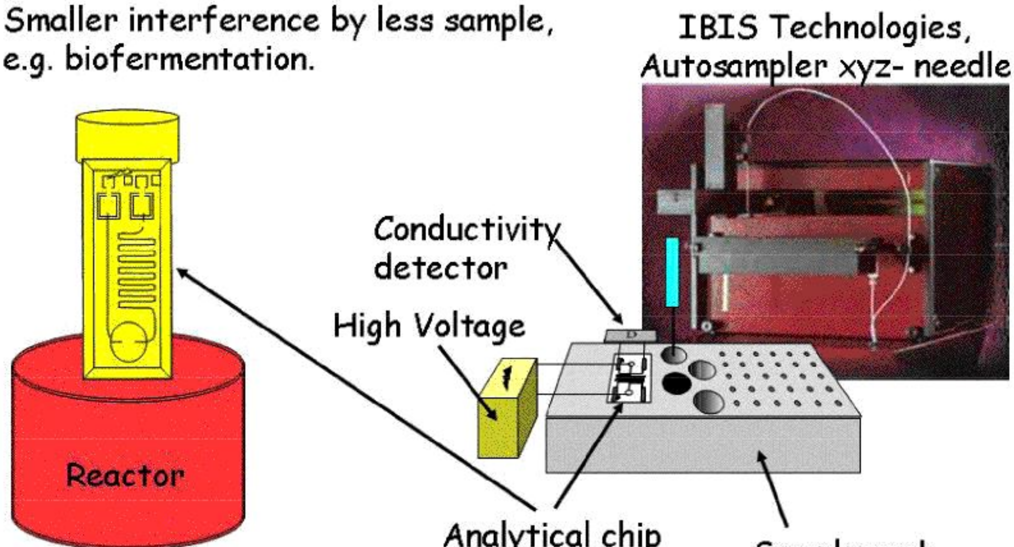


Ekstrom et al., Anal Chem 2000; 72:286–93.

Process monitoring sample handling?

Programmable liquid handling

- Operator independent efficient/fast reaction kinetic probing.
- Smaller interference by less sample, e.g. biofermentation.

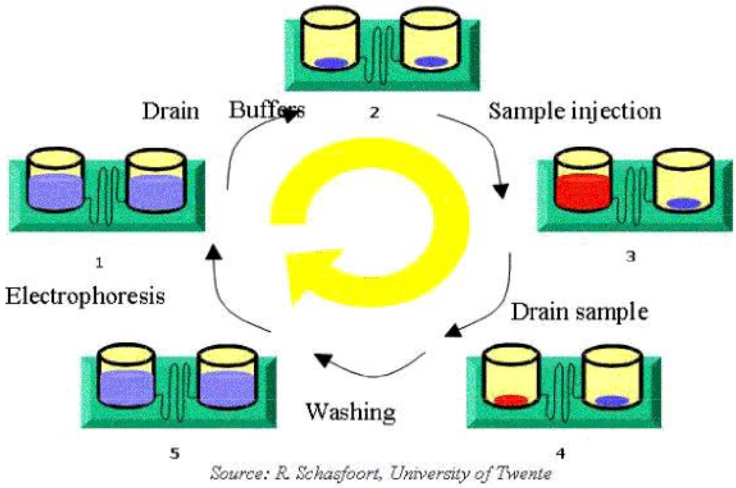


Source: R. Schasfoort, University of Twente

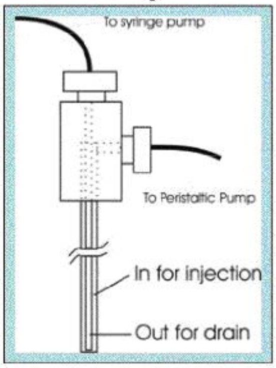
Handling protocol at the scale of 0.5 to 10µl

Head-end injection

- Autosampler interface to chip



Autosampler-
Needle injector



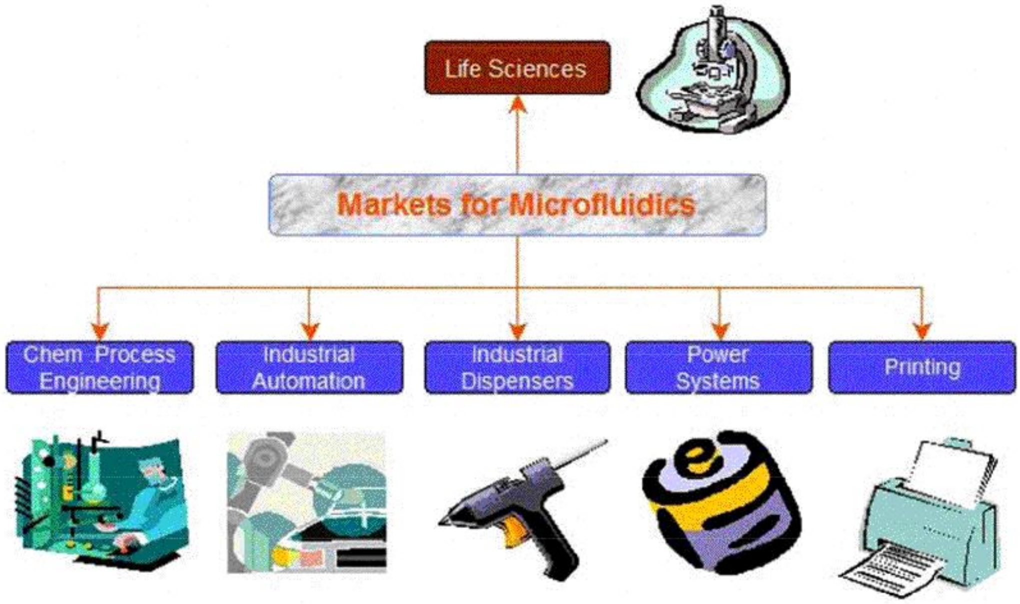
"Double needle"

High-risk application

- High Pressure
- High electrical fields
- Toxicity

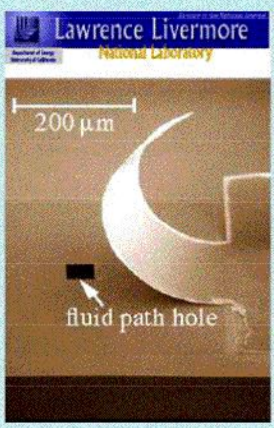
Biodefense

Microfluidic markets



Topics in this section

Components

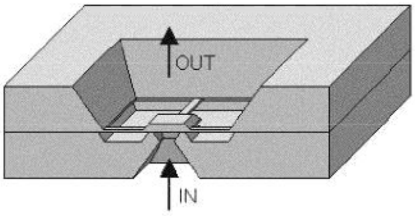


Structural elements and integration

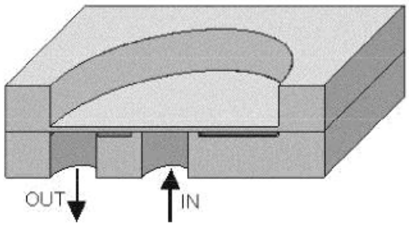
- Components
  - Valves
  - Pumps
  - Actuation-based (active) mixers
  - Flow sensors
  - Micro, nano, picoliter dispensers

Passive microvalves etched in silicon

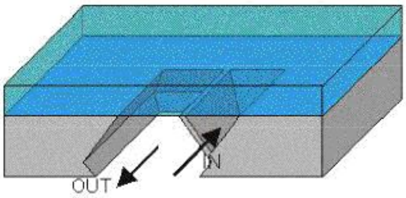
Bossed Valve



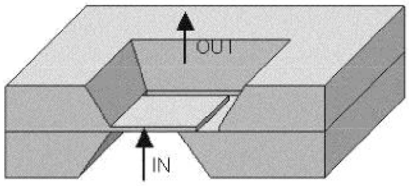
Membrane Valve



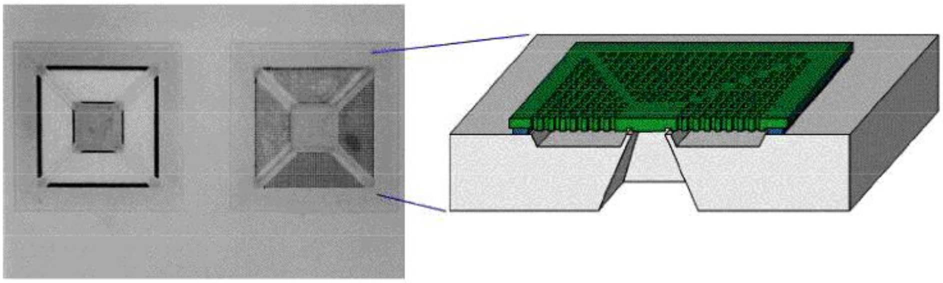
Duckbill Valve

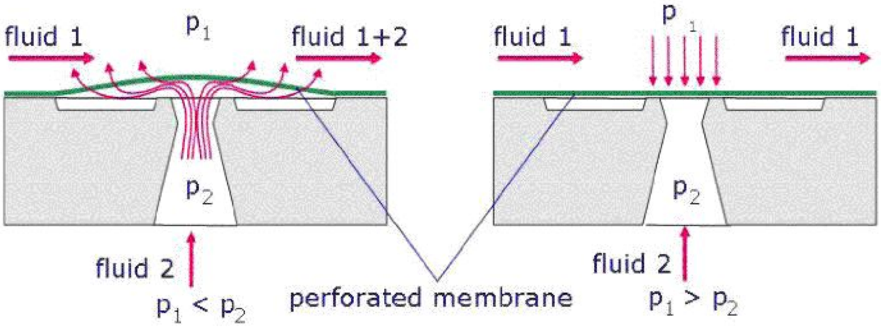


Flap Valve



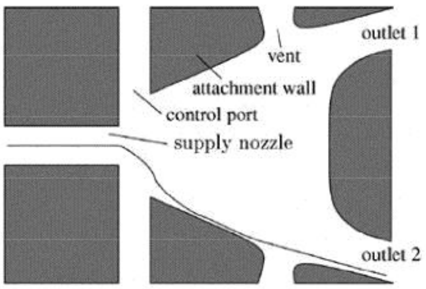
Injector valve



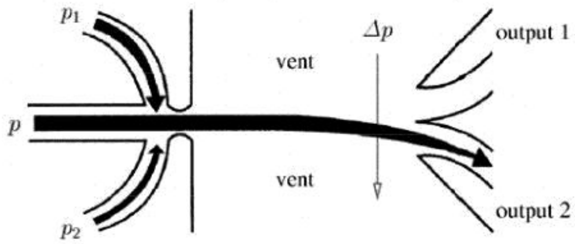


Passive valve computing

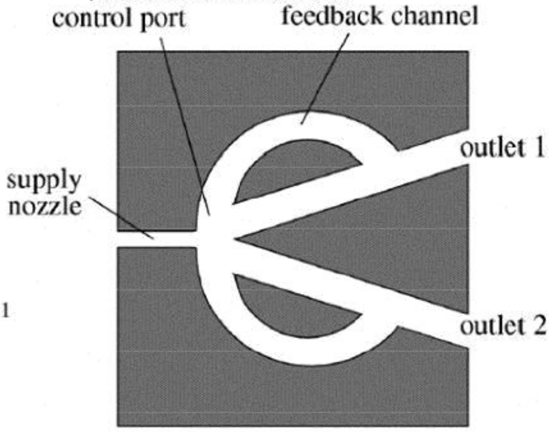
Microfluidic flip-flop
(amplifier based on Coanda effect_



Microfluidic proportional amplifier

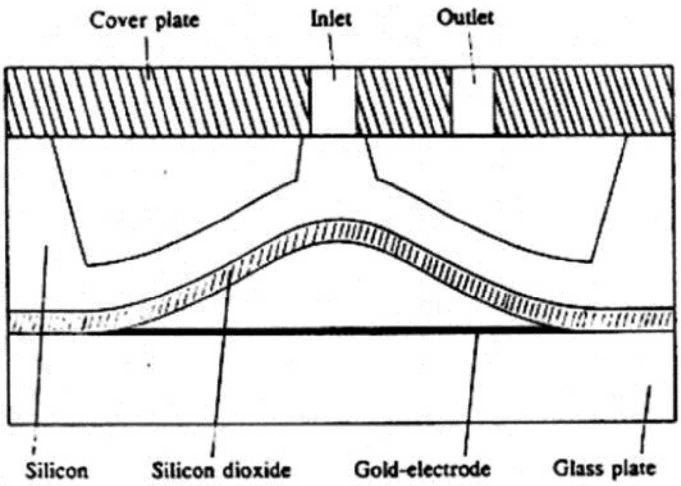


Fluidic micro-oscillator with
feedback channel



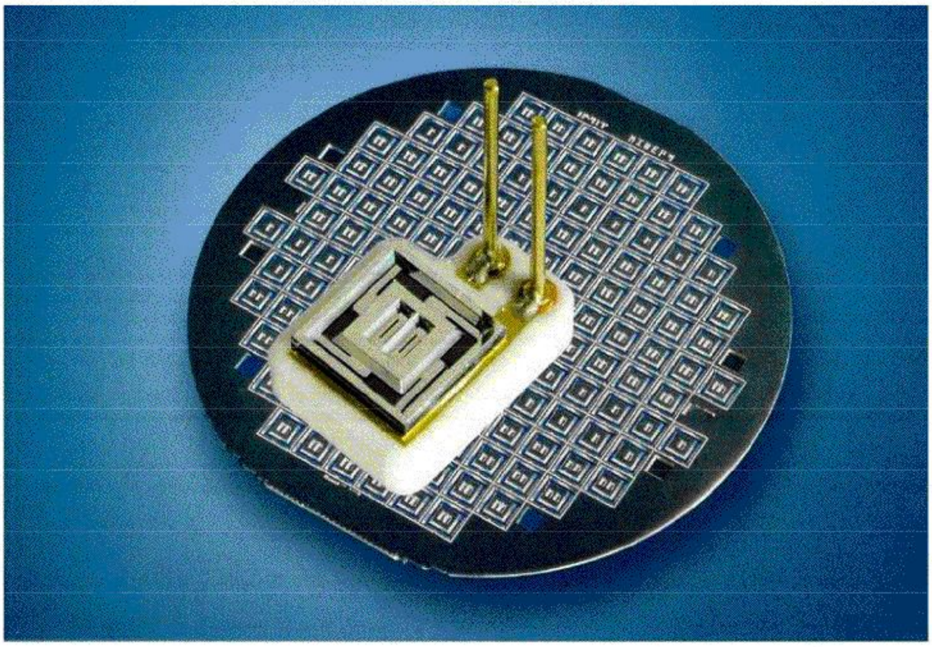
Tae-Hyun Kim et al., J. Micromech. Microeng. **8** *(1998) 7–14*

Electrostatic microvalve

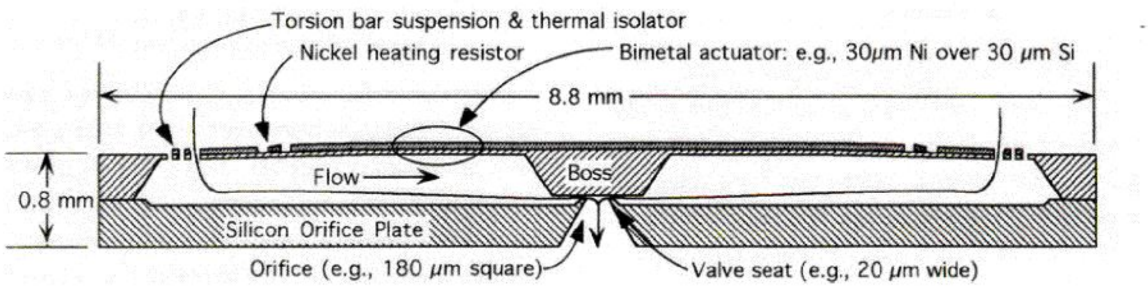


J. Branebjerg and P. Gravesen, *A New Electrostatic Actuator providing improved Stroke Length and Force*, Proc. MEMS Workshop 1992, p 6

Silicon-based electrostatic microvalves



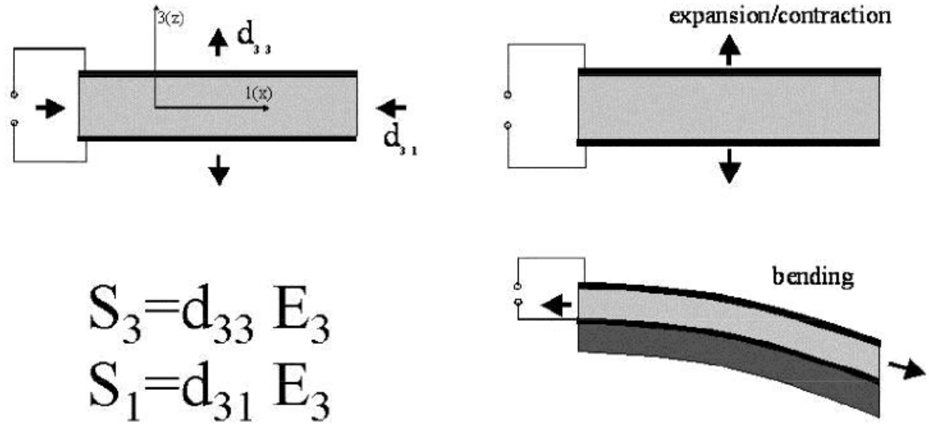
Thermal (bimetal) microvalve



Source picture: Hewlett-Packard Company, Palo Alto, CA, USA

H. Jerman, Electrically-Activated, Micromachined Diaphragm Valves Techn. Digest Hilton Head Workshop, 1990, p. 65

Piezoelectric actuation principle



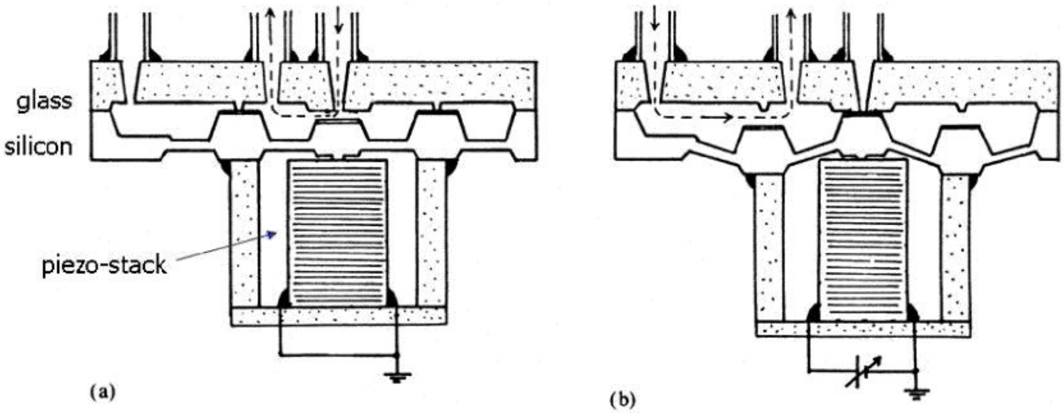
$$S_3 = d_{33}\, E_3$$
$$S_1 = d_{31}\, E_3$$

S = strain = dL/L, relative Length change

E = electric field

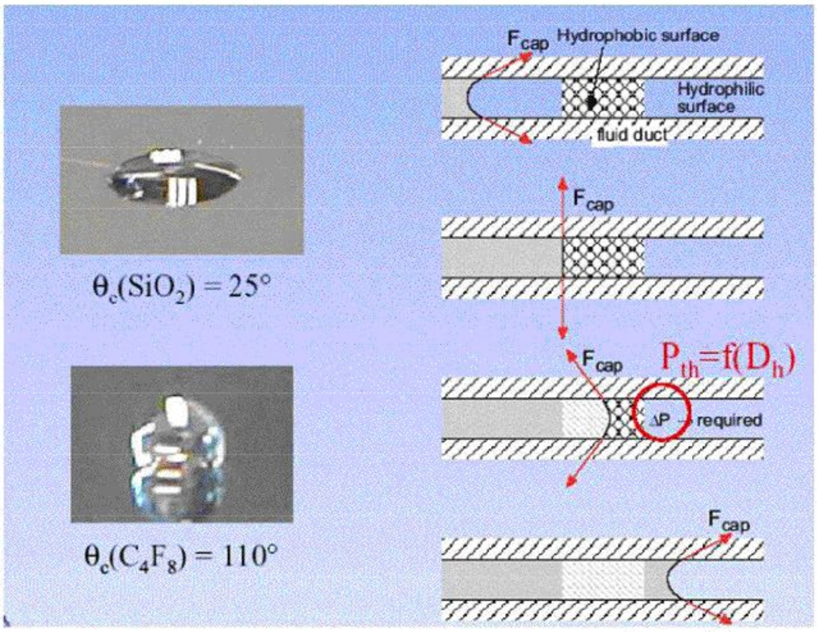
example: for PZT d_{31} = -75 nm/V; d_{33} = 223 nm/V

Piezoelectric 3-way microvalve



M. Esashi, *Integrated micro flow control systems*, Sensors & Act. A21-23, 1990, p.161

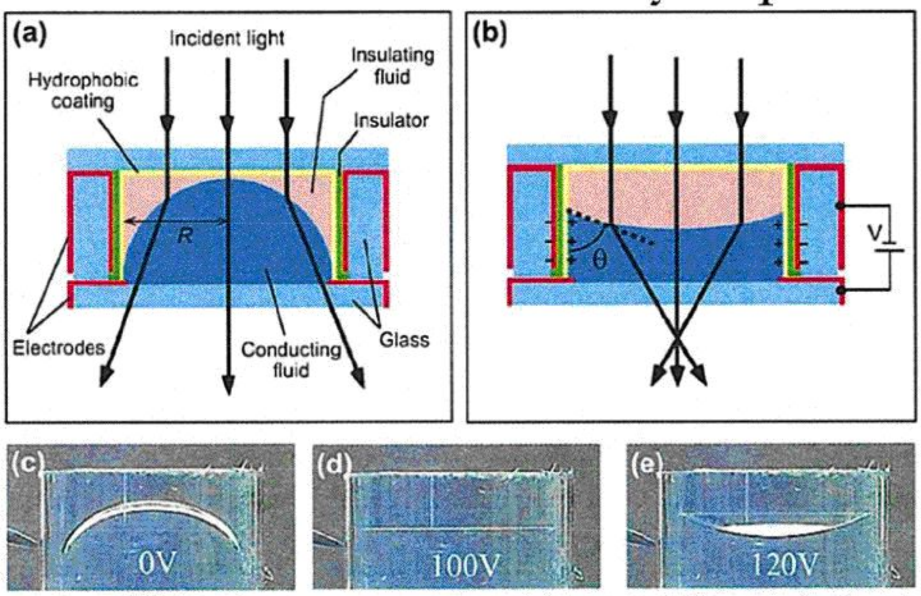
Hydrophobic valving



Source: unknown

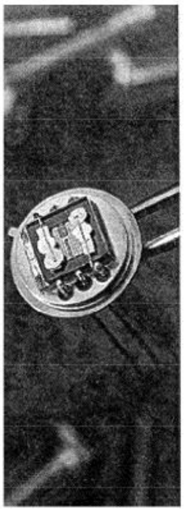
Electrical actuated application of hydrophobicity

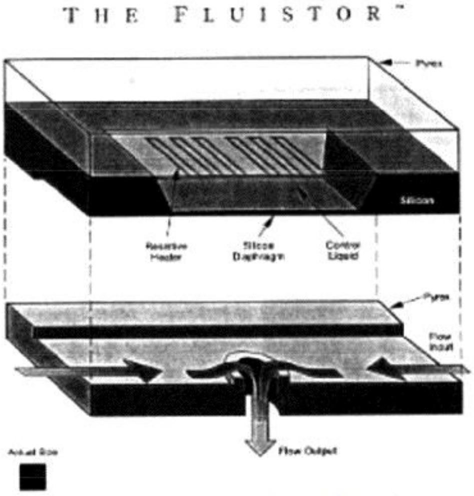
- Variable focus liquid lens

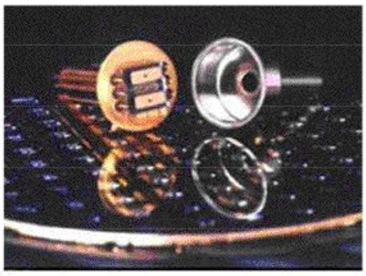


S. Kuiper e.a. Appl. Phys. Lett. 85, 2004, 1128

Phase-change microvalve







Source: Redwood MicroSystems, Menlo Park CA, USA - www.redwoodmicro.com

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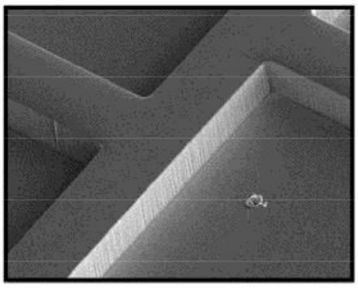
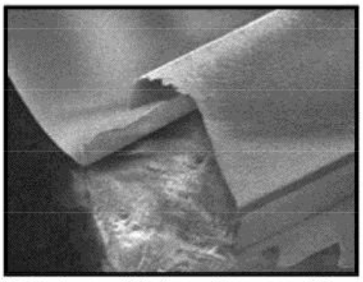
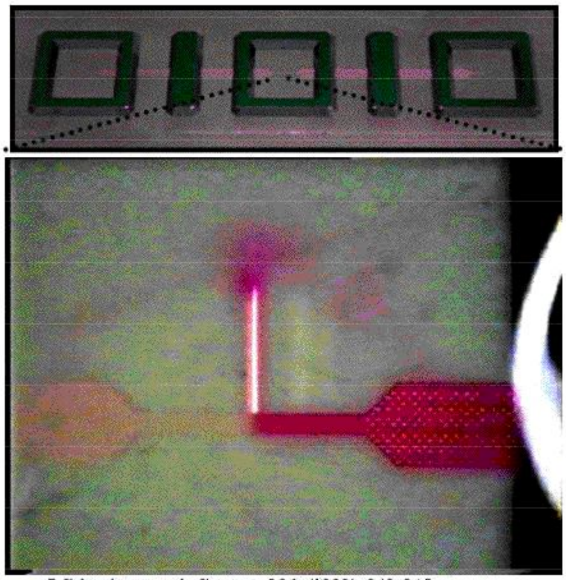
Electrokinetic valving: FlowFET

<u>μ-Transparent Integrated Channel</u>



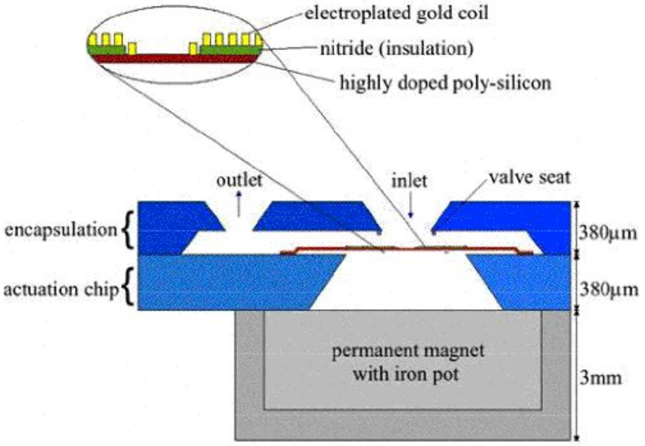




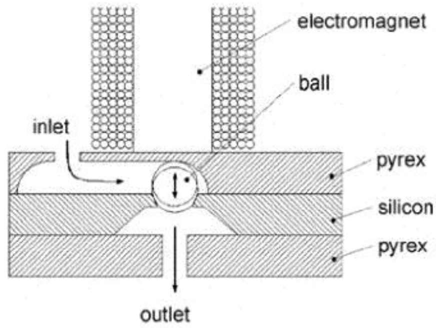
W. Tierkstraa, PhD thesis, University of Twente

R.Schasfoort et al., Science, 286, (1999), 942-945.

Electromagnetic microvalve



Membrane valve



Ball valve

Source: A. Meckes, IMSAS, University of Bremen, Germany
O. Krusemark, Technische Universität Hamburg-Harburg, Hamburg, Germany

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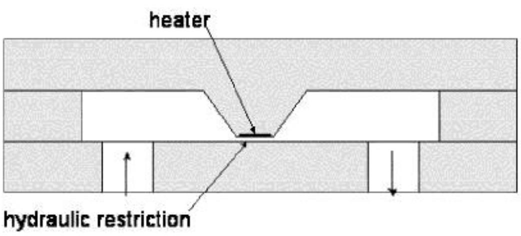
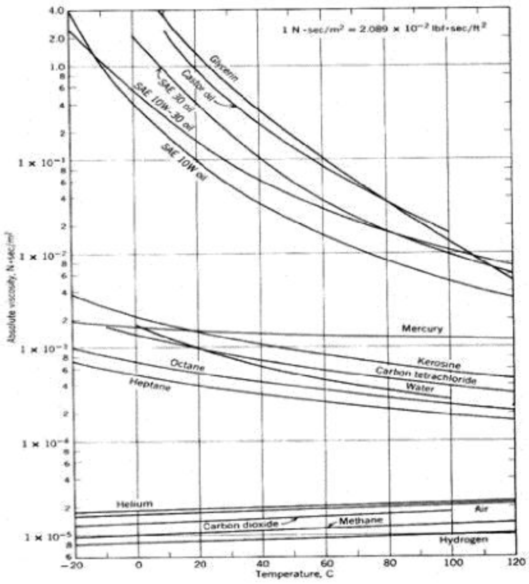
Thermo-viscous valve

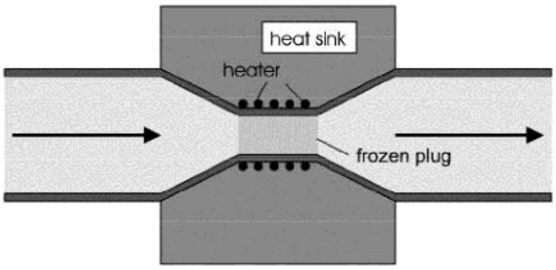
- Principle: viscosity variation of liquid due to temperature changes

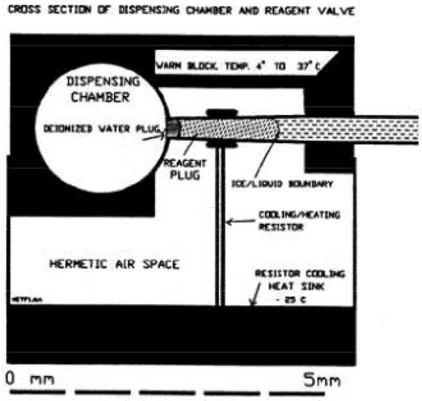


Source: *A. Klein, Dresden University of Technology, Germany*



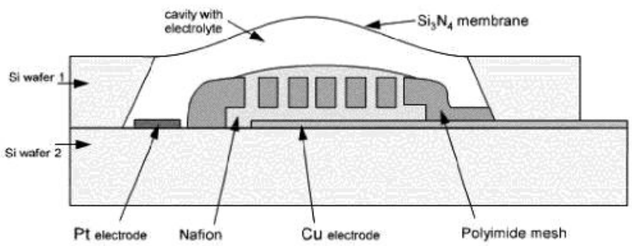
Freeze-melt valve

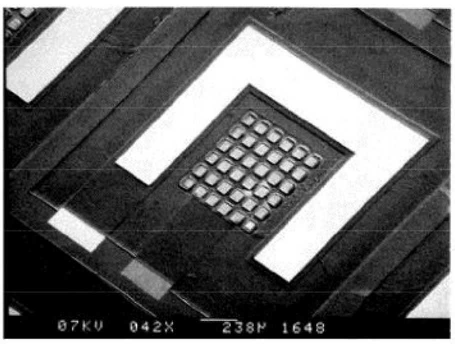


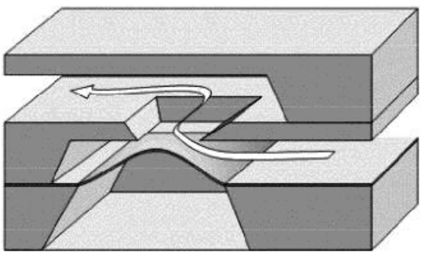


N. Kaartinen, Proc. IEEE MEMS workshop, San Diego, CA, USA, 1996, p. 395

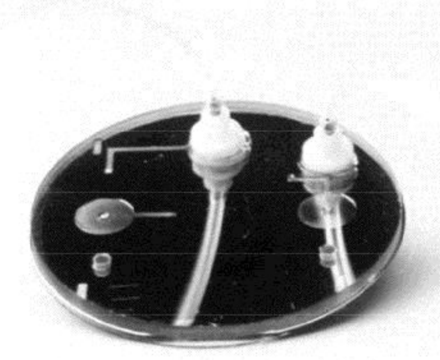
Electrochemical microvalve

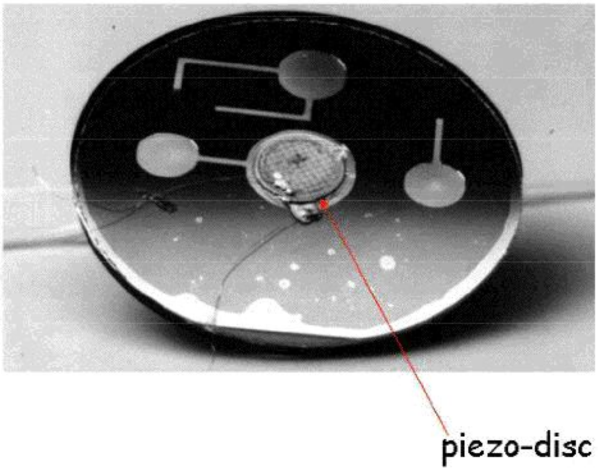






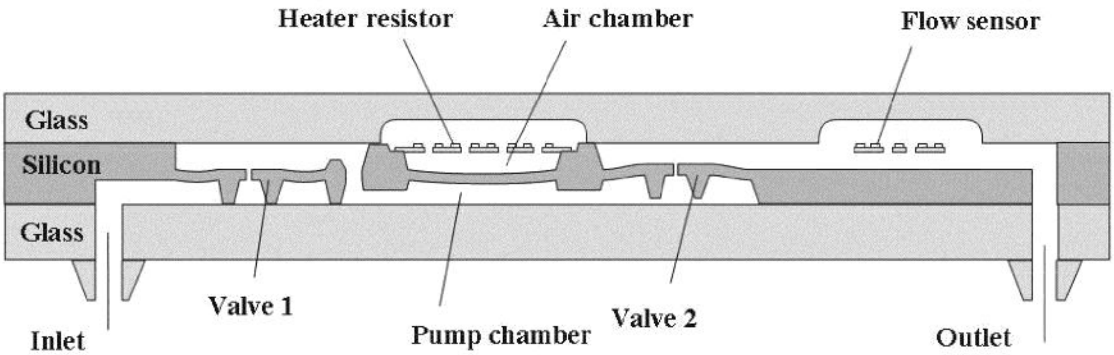
Piezoelectric micropump

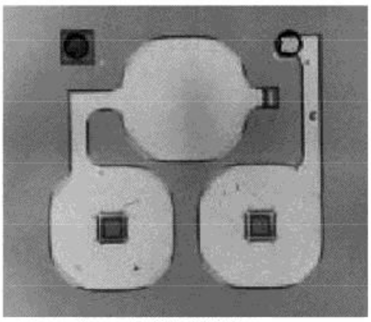


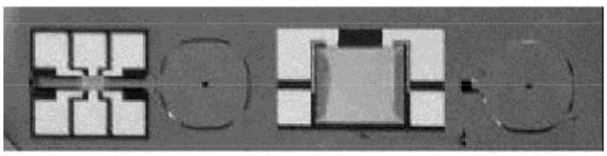


H.T.G. van Lintel, F.C.M. v.d. Pol and S. Bouwstra,
A piezoelectric Micropump based on micromachining of silicon, Sensors & Act. 15, 1988, p. 153.

Thermo-pneumatic actuated micropump



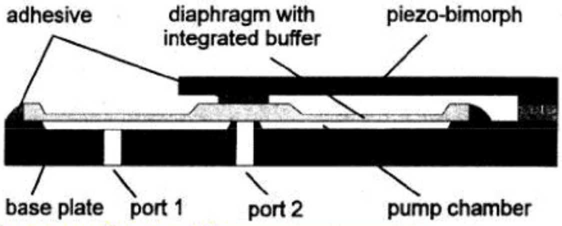


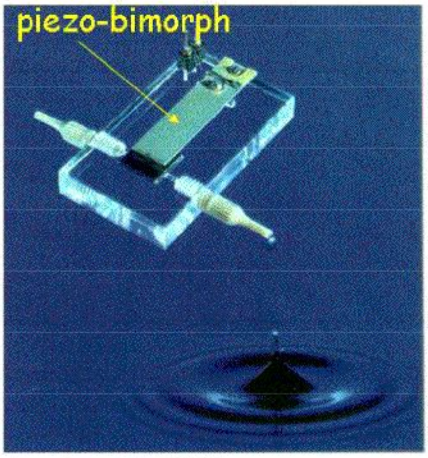


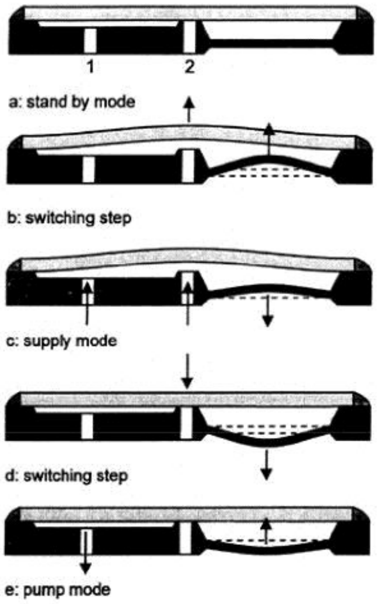
Silicon etching + anodic wafer bonding

Micro dosing system, 1992, University of Twente

Piezoelectric bimorph micropump

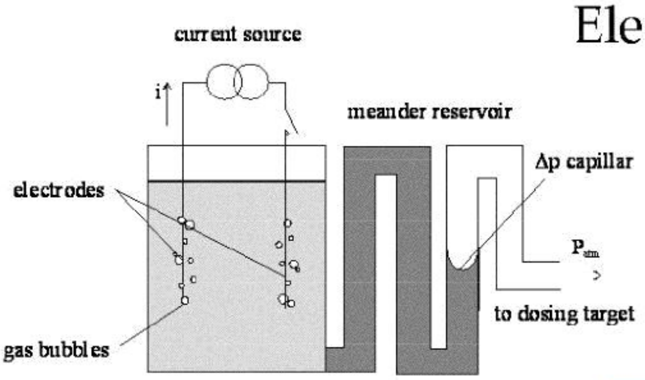


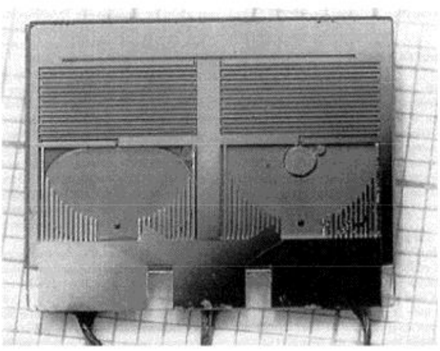


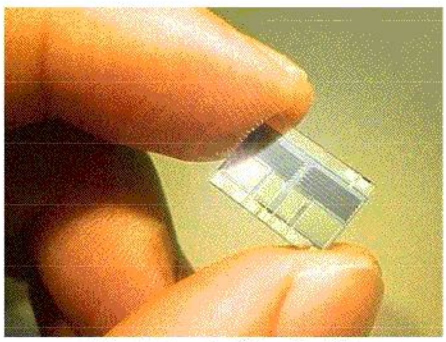


M. Stehr, S. Messner, H. Sandmaier and R. Zengerle,
A new micropump with bidirectional fluid transport and selfblocking effect,
Proc. IEEE MEMS workshop, 1996, p. 485

Electrochemical pump



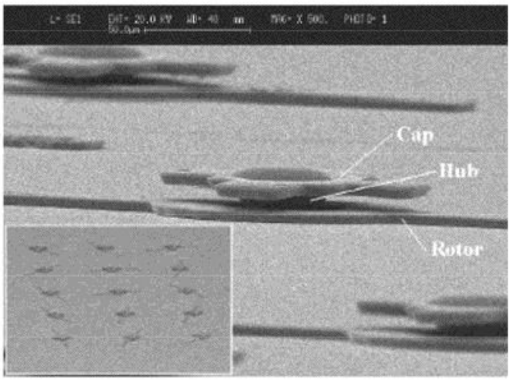


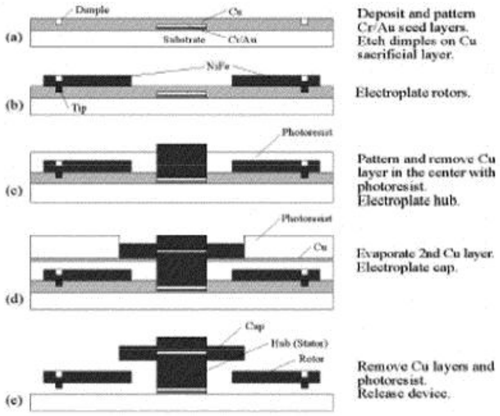


A. Sprenkels et al., University of Twente

Surface micromachined mixer array

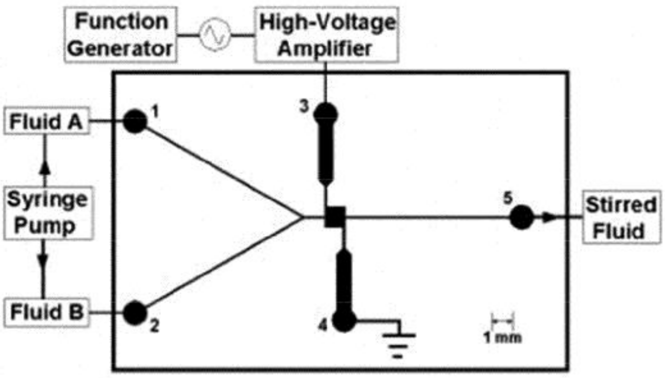
- Stirring with a micromachined rotor: complete mixing in 55s

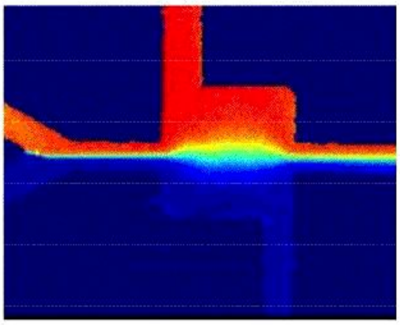




L.-H. Lu, K.S. Ryu and C. Liu, Proc. Micro Total Analysis Systems 2001, pp. 28-30.

Electrokinetic instability mixer





Source: Oddy et al., Stanford Univ., Anal. Chem. 73(24), 2001, 5822

Fluidic sensors

Physical parameter sensing

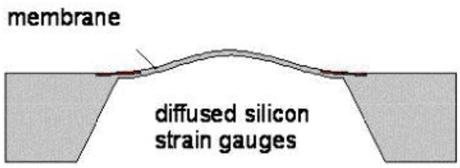
- Pressure sensors
- Flow sensors
- Temperature sensors
- Viscosity sensors
- Density sensors
- Cytometers
- Thermal conductivity sensors
- Optical absorption sensors

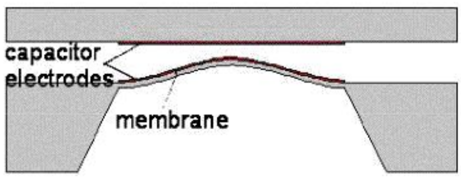
Chemical parameter sensing

- IsFET
- ChemFET
- Electrical conductivity sensors
- etc...

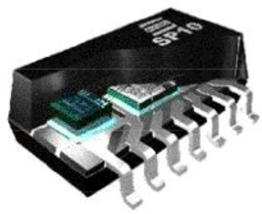
Membrane-based gas pressure sensors

- Pressure sensors with
- piezo-resistive read-out
- capacitive read-out



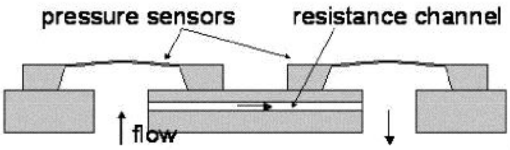


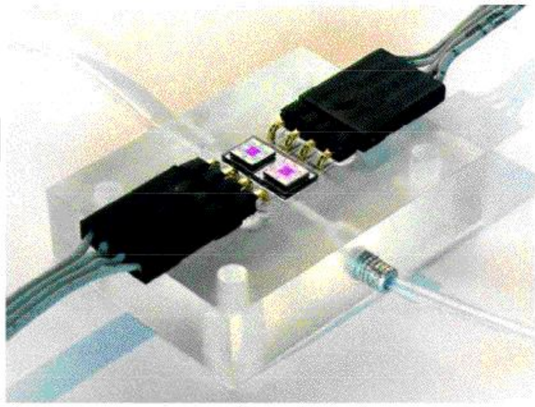
Commercial activities: Honeywell, U.S.A.
Motorola, U.S.A.
NovaSensor, U.S.A.
SensoNor, Norway
Kulite Sensors Limited, U.K.



Membrane-based liquid pressure sensor

- Viscous drag flow sensor: measures the dissipated kinetic energy in a hydraulic resistor by means of pressure drop sensing





Source: R.E. Oosterbroek, MESA+ Research Institute - Transducers Technology Laboratory

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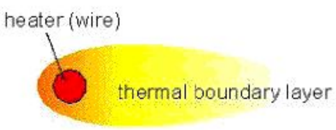
Thermal flow sensing principles

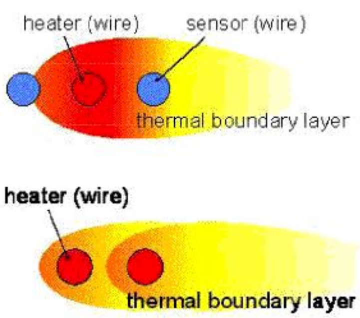
- Hot wire anemometer

Measures:
power needed to keep constant temperature.



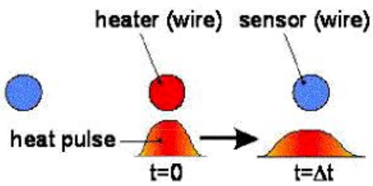
- Heat transfer

Measures: Heat transfer from heater to sensors or balancing temperature of two heaters/sensors.



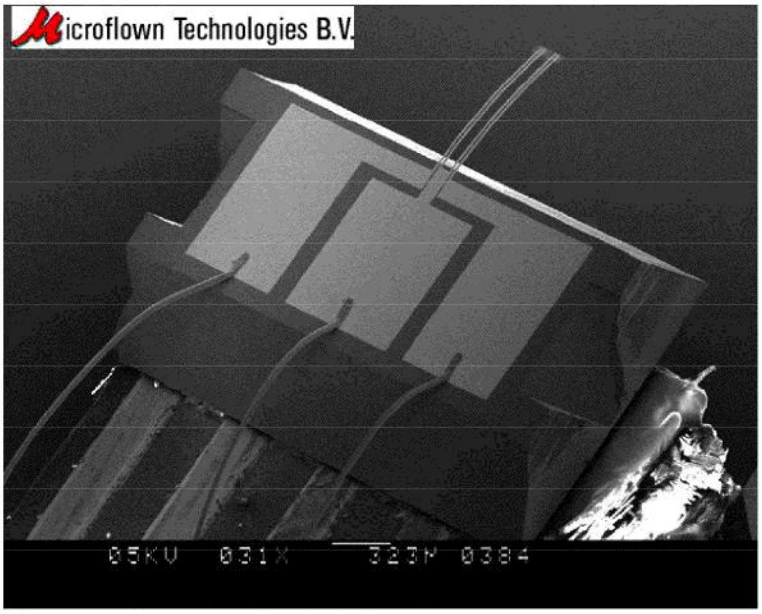
- Time of flight

Measures: Time between generating a heat pulse and sensing the pulse at some distance.



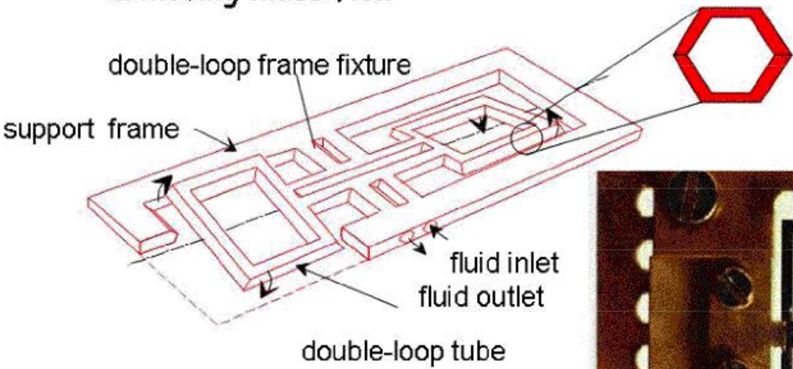
Microphone-based gas flow sensor

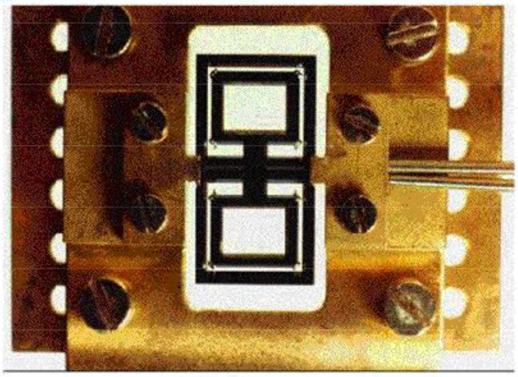
Planar intergrate "hot-wire anemometer"



Fluidic flow sensors

- Coriolis flow sensor: measures the induced Coriolis force on a moving mass flow



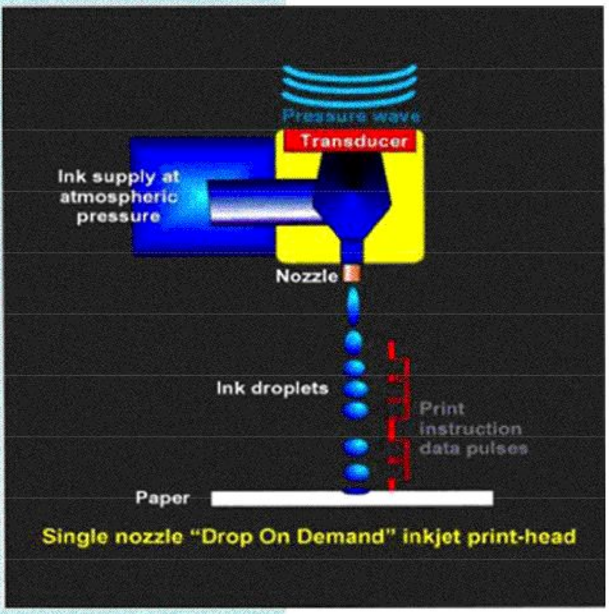


Source: P. Enoksson, Royal Institute of Technology, Dept. of signals, sensors & systems, Stockholm, Sweden

Examples of microfluidic "platforms"

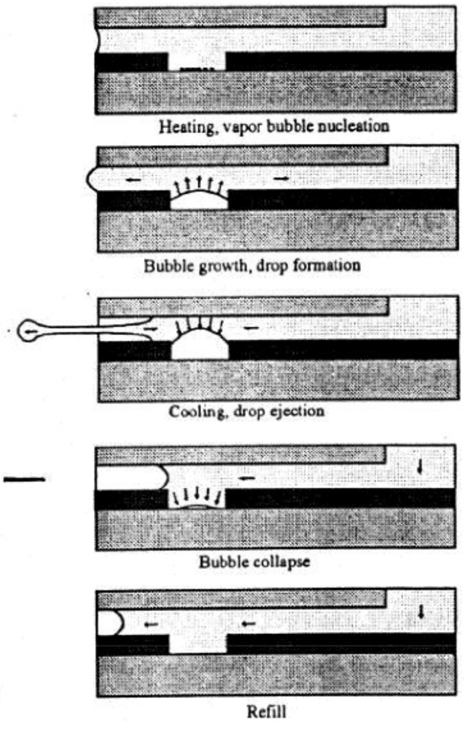
Topics in this section

Heart of fluidic platforms:
The dispensers.



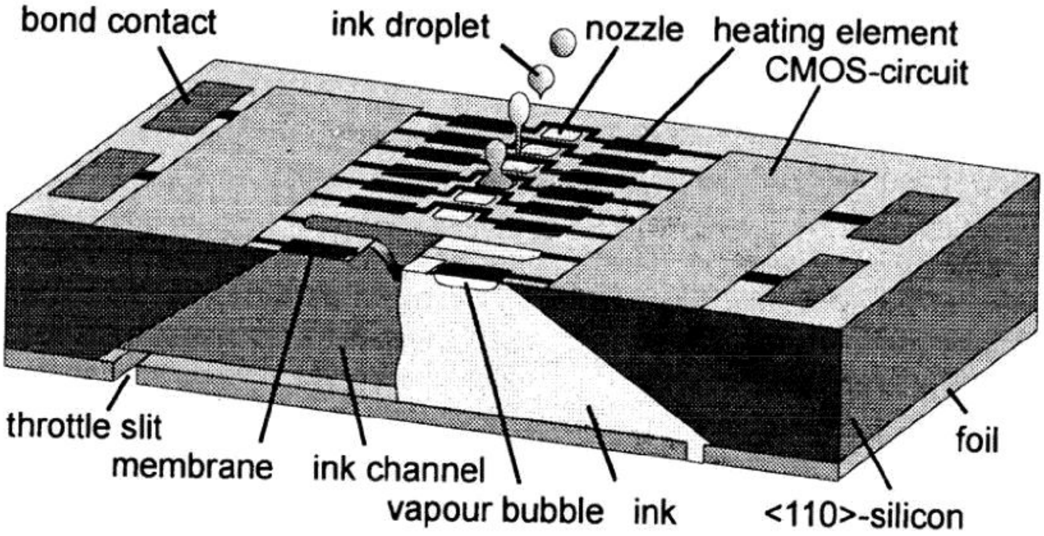
- Dispensers
- Other devices

Thermally actuated inkjet



M.P. O'Horo, N.V. Deshpande and D.J. Drake,
Drop generation process in TIJ printheads,
Proc. 10th Int. Congress on Advances in non-impact printing technologies, Soc. Imaging, Sc. and Techn. (IS&T) 1994, p. 418

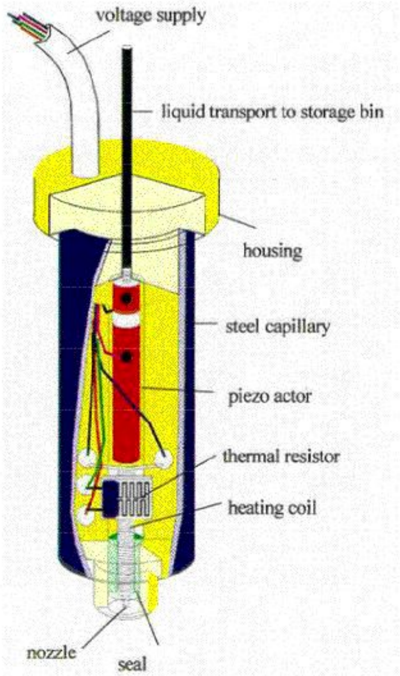
Thermally actuated inkjet

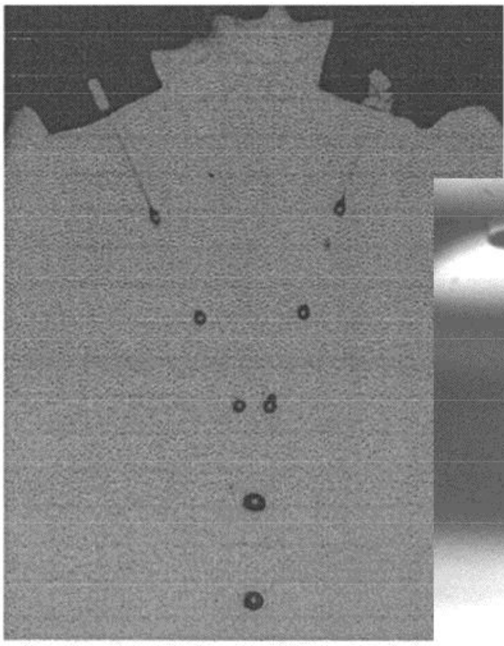


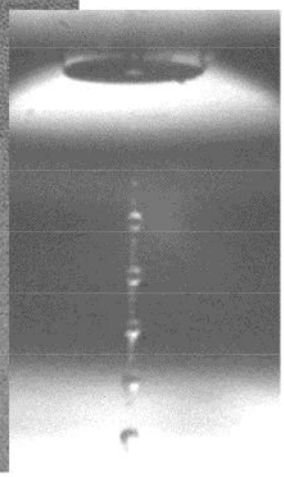
Source: *M. Haruta, Canon Inc., Japan*

3.3. Examples of microfluidic "platforms"

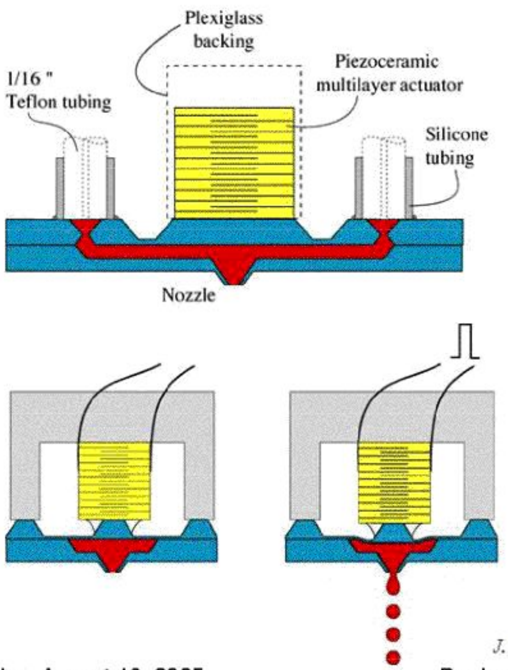
Piezoelectric dispenser - tube format

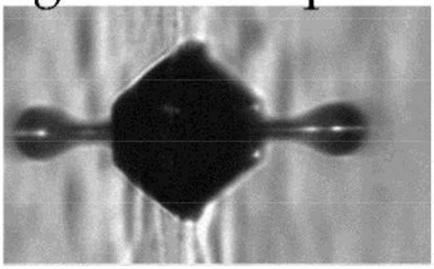


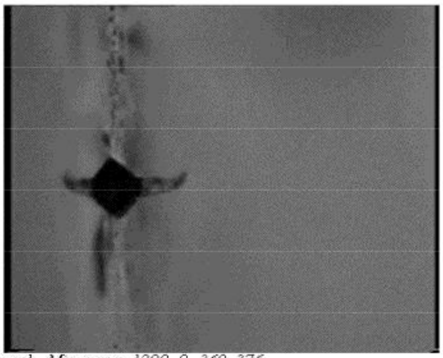




Piezoelectric flow-through microdispenser



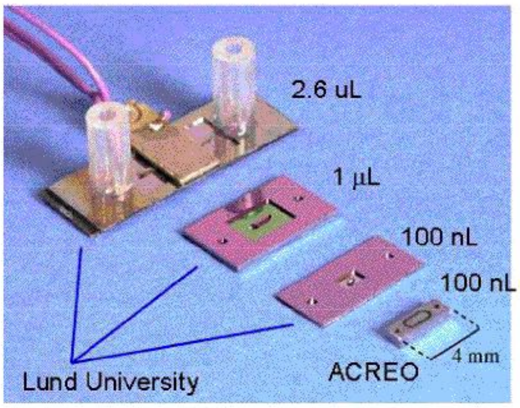




J. Micromech. Microeng. 1999, 9, 369-376

Microdispenser development

Dispenser platform



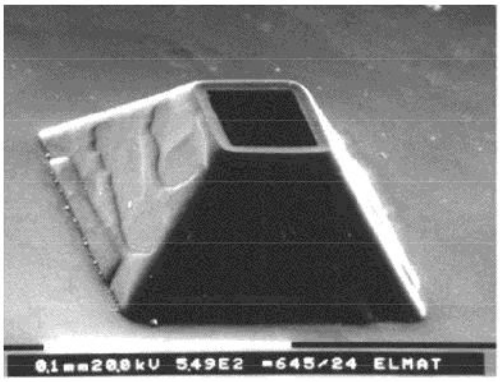
Source: Th. Laurell

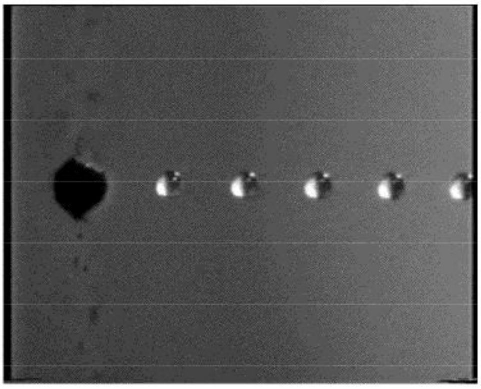
250-100 nL inlet to nozzle
Typical droplet volume: 50-100 pL
Nozzle dimensions: 30-50 µm
Dispense rate: ≤ 9 kHz
Viscosity interval
- 0.36 mPas (25°C) acetone
- 65 mPas (25°C) gycerol/water

Surface tension
- 22 mN/m, ethanol
- 73 mN/m, water

Component to platform

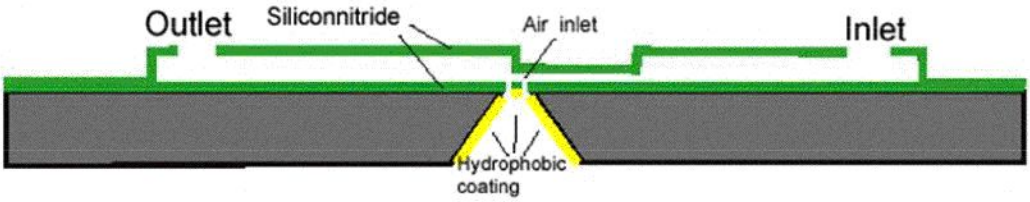
- Ejector nozzel and operation





Source: Th. Laurell

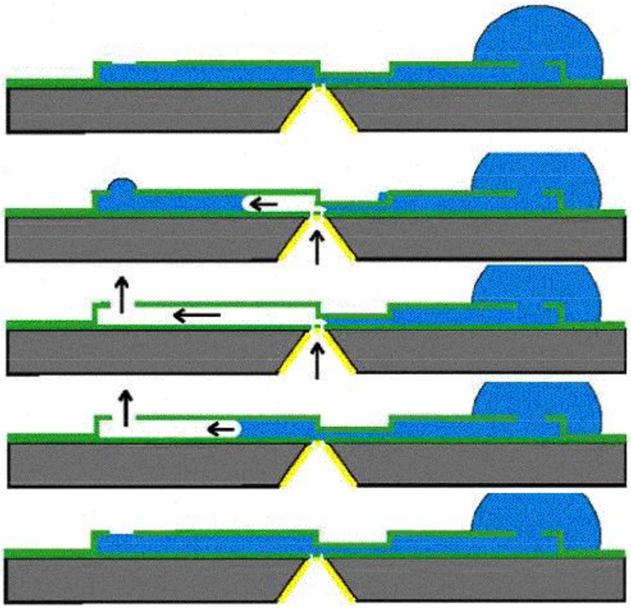
Capillarity-defined picoliter dispenser



- capillary pressure: $Dp = 2\ g_{lg} \cos q_c / h$
- surface micromachined microchannels
- injection of gas bubble
- direction by geometric asymmetry in channel height
- very small and precise stroke volume (pl)
- hydrophobic patches for gas inlet/outlet

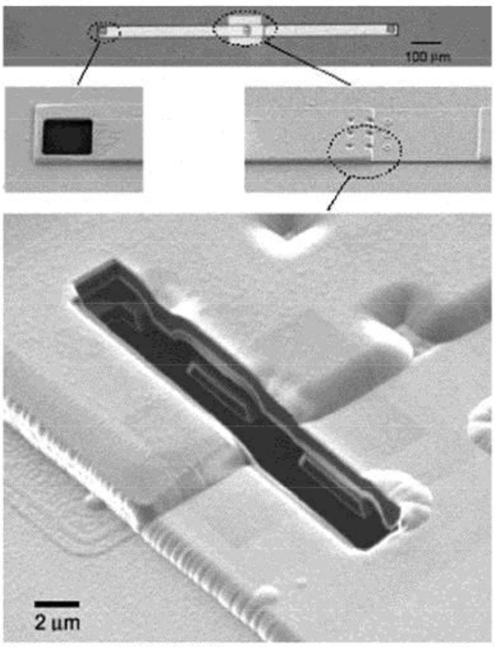
N. Tas et al, University of Twente

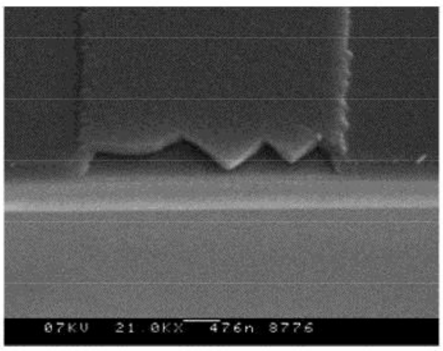
Picoliter bubble dispenser schematic



N. Tas et al, University of Twente

Nano fabrication results

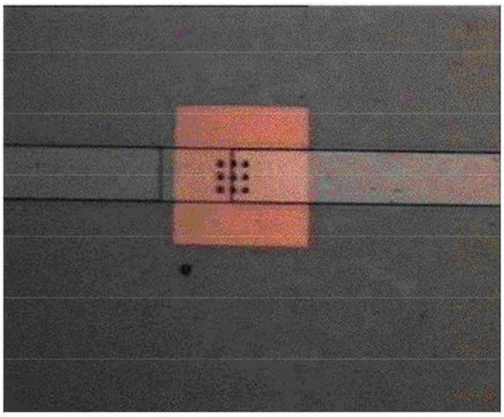


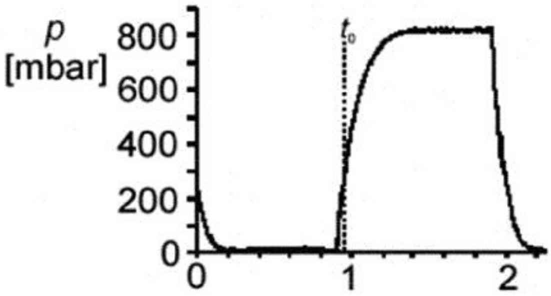


N. Tas et al, University of Twente

3.3. Examples of microfluidic “platforms”

Picoliter dispensing operation





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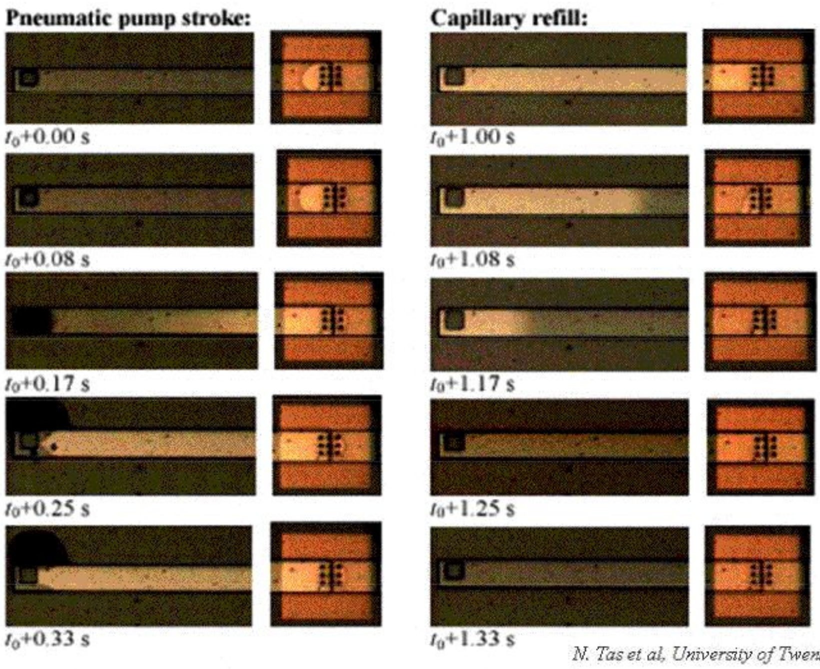
3.3. Examples of microfluidic “platforms”

Picoliter dispensing operation



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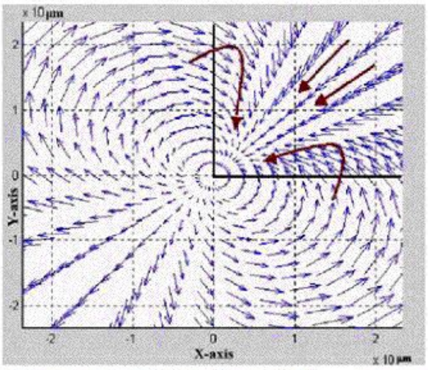
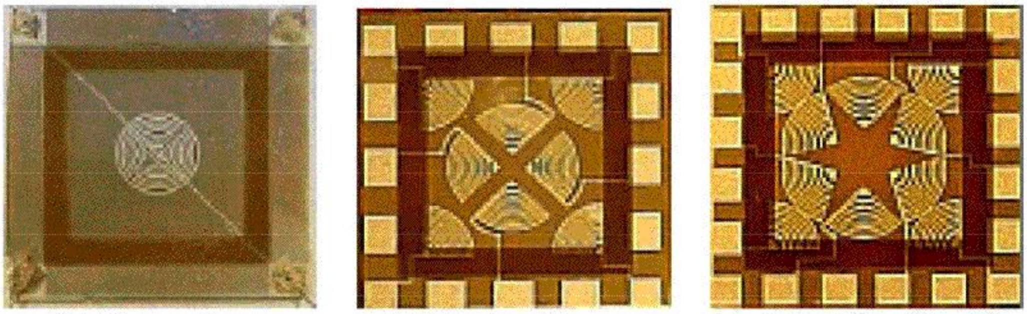
3.3. Examples of microfluidic “platforms”

Acoustic particle handling





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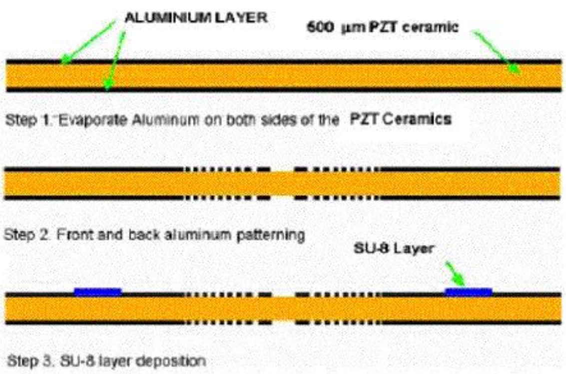
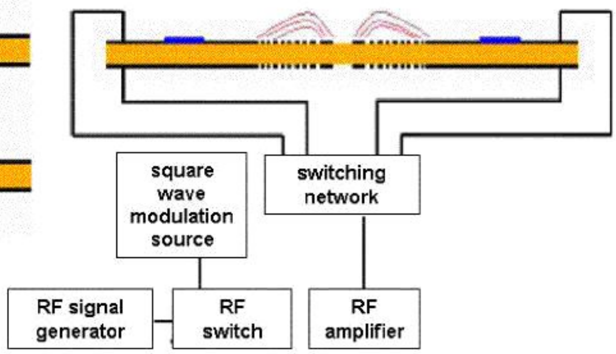
3.3. Examples of microfluidic “platforms”

Fabrication and test set-up





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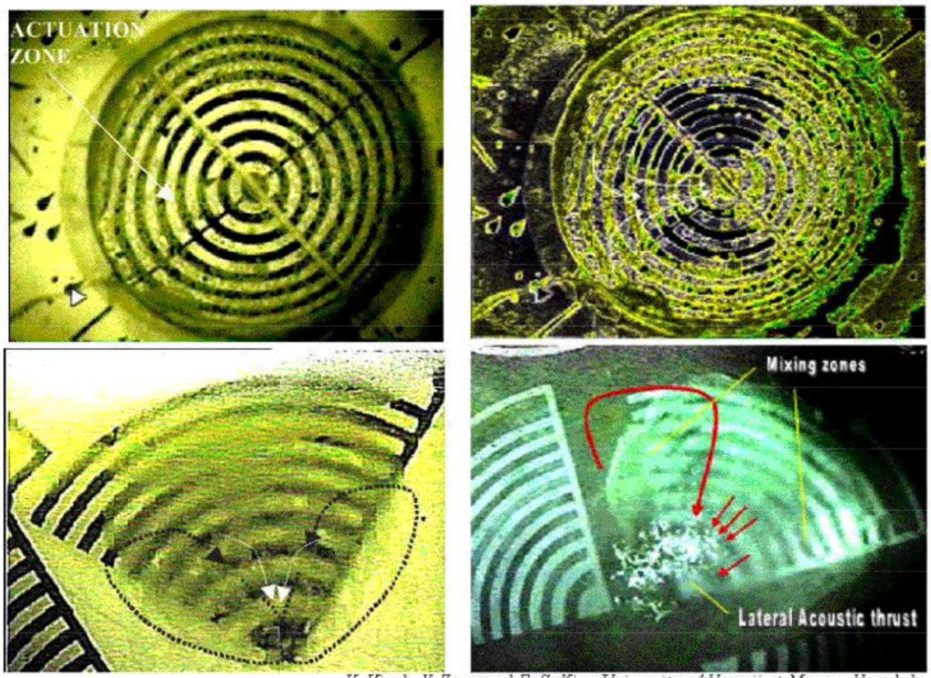
3.3. Examples of microfluidic "platforms"

Particle movement



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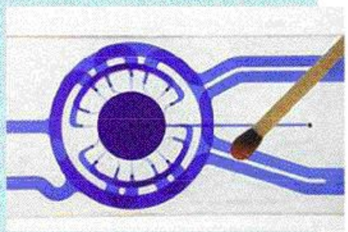
Outlook: Future developments

Microfluidics…
…Nanofluidics.

- Nanofluidics is on its way….

Summary



Source: IMM "Zyklon mixer"

- Many components were identified to be "nanofluidics" since they are dispensing nanoliter droplets or fluid flows of nanoliter/time unit.
- Flow control components often as stand-alone units developed.
- Components are assembled as hybrid microfluidic systems or platforms for many applications, e.g., in analytical chemistry and medical diagnostics.