Silicon Microchannel Cooling

.. and related microfluidic and microcooling topics

Han Gardeniers
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20th January 2003

Outline

- short overview MESA
- short overview BIOS / Lab-on-a-Chip
- buried microchannels:
  - micromachining process
  - silicon nitride and polysilicon
  - applications: pipette for mechanical DNA study
- cryogenic microcooler project overview

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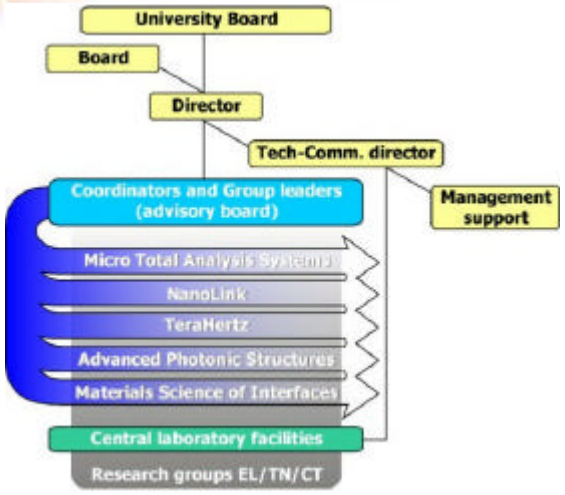
Organisational Overview



MESA+ Research Groups

Chem. Eng.:	Chemical Analysis (CA)
	Inorganic Materials Science (IMS)
	Materials Science and Technology of Polymers (MTP)
	Supra Molecular Chemistry and Technology (SMCT)
Electr. Eng.:	**Biosensors / Lab-on-a-Chip (BIOS)**
	Semiconductor Components (SC)
	Computer Architecture, Design & Test for Embedded Systems (CADTES)
	Integrated Circuit Design (ICD)
	Systems and Materials for Information Storage (SMI)*
	Lightwave Devices (LDG)*
	Transducers Science and Technology (TST)
Appl. Phys.:	Biophysical Techniques (BFT)
	Computational Materials Science (CMS)
	Systems and Materials for Information Storage (SMI)*
	Lightwave Devices (LDG)*
	Low Temperature Physics (LT)
	Optical Techniques (OT)
	Solid State Physics (VSF)
	Complex Photonic Systems (COPS)
Appl. Math.:	Applied Analysis and Mathematical Physics (AAMP)

Micro and nanofluidic devices for chemical and biomedical applications

Current research
BIOS Lab-on-a-Chip group

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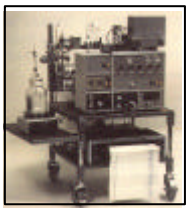
(also with Micronit Microfluidics B.V.)

1st November 2002

Development of µTAS/LOC concept

1970



1980

1990

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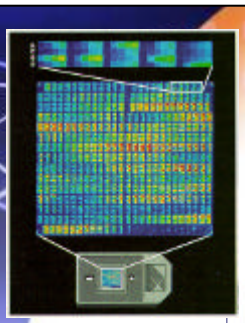
2000 and beyond: Lab-on-a-Chip



ACLARA

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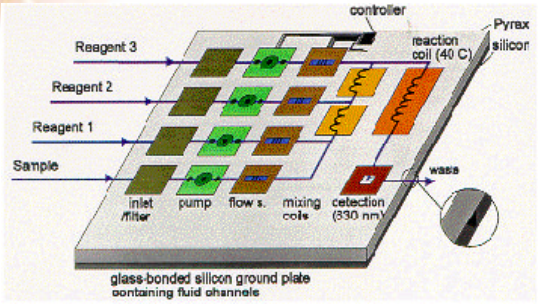
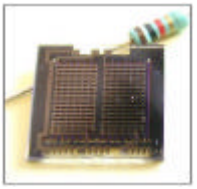
Lab-on-a-Chip: motivation

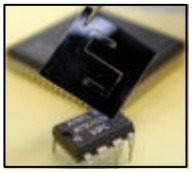
General reasons for miniaturisation:

- Reduced weight (portable)
- Reduced size (implantable, integratable)
- Reduced price (batch fabrication, disposable)
- Reduced consumption of chemicals (expensive or limited source)
- Reduced energy consumption
- Reduced production of waste (toxic products)
- Reduced flow (accurate dosing)
- Increased heat exchange
- Fast mass transport
- Integration of sensors
- Parallellisation
- Automation

Micro Flow Injection Analysis System for Ammonia determination

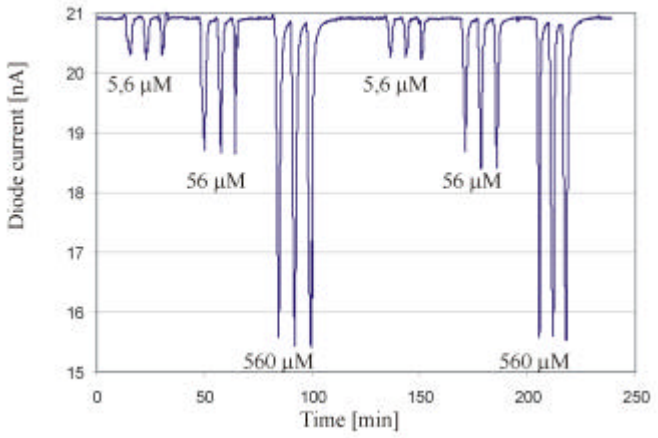






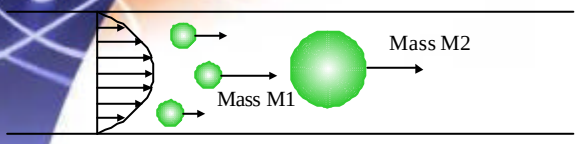
from: Ph.D. thesis Theo Veenstra

Measurements modular system

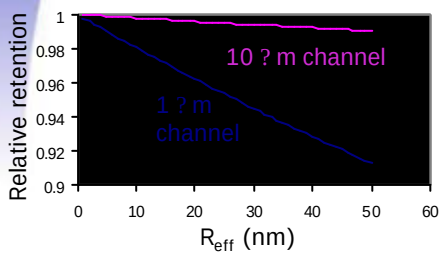


R.M. Tiggelaar et al., Sens. & Act. B in press

Hydrodynamic chromatography chip



Separation is enhanced
by smaller channel height



from: Ph.D. thesis Marko Blom

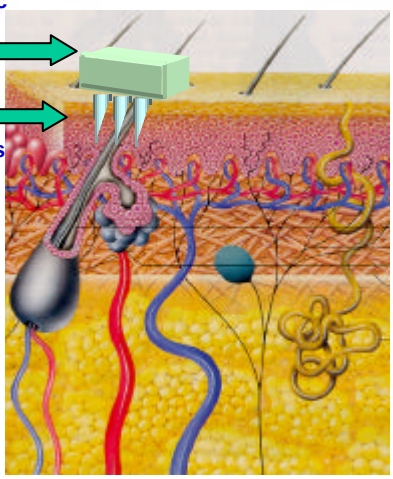
Separation of 26, 44, 110, 180 nm fluorescent polystyrene particles and a marker

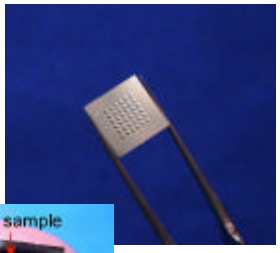
Anal. Chem. 74, 2002, p.3470-3475, Sens. & Act. B 82 (2002) pp. 111-116

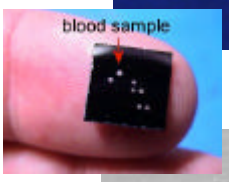
Silicon micromachined hollow microneedles for trandermal liquid transport

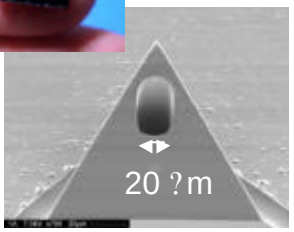
Diagnostic sensor or drug container

Hollow microneedles









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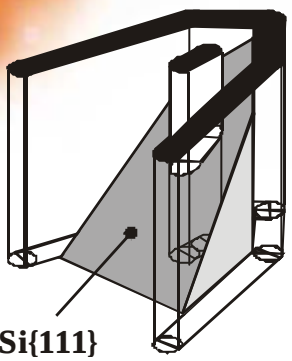
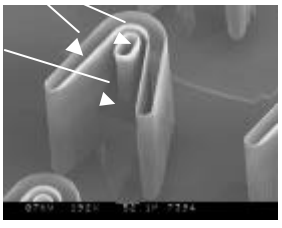
Fabrication process out-of-plane needles

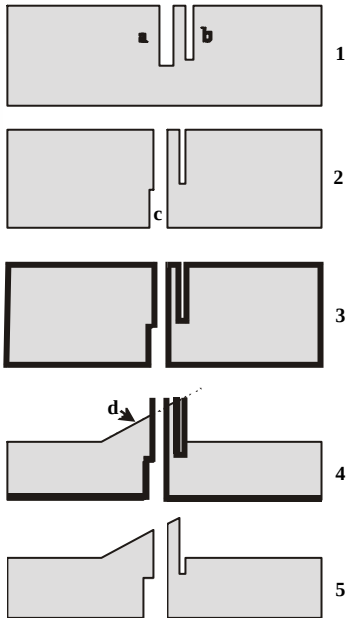


Si{111}

DRIE etch

KOH etch





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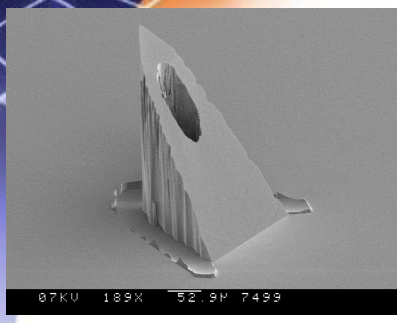
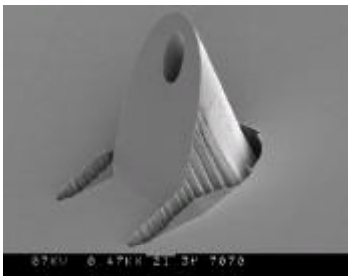
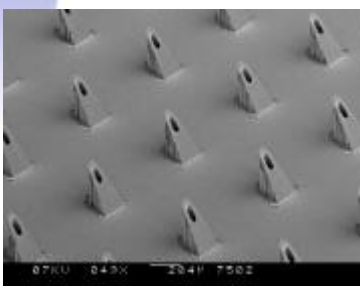
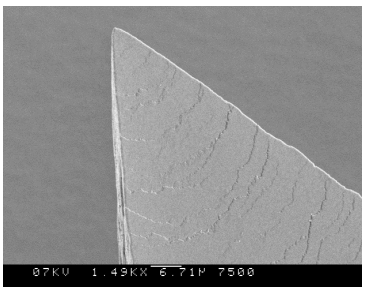
Proc. MEMS 2002, pp. 141-146; submitted J. MEMS

Resulting microneedles

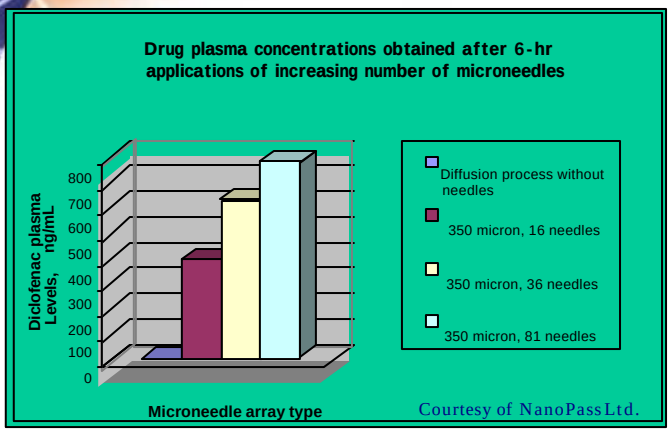






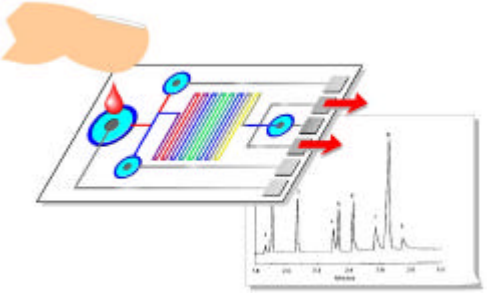


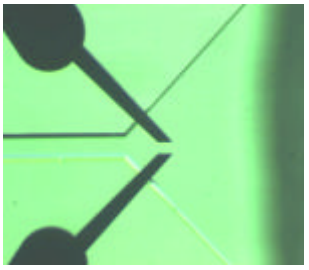
Application of Sodium Diclofenac to rats



Microsystem for lithium therapy monitoring

glass chip for capillary electrophoresis with end-column integrated conductivity detection

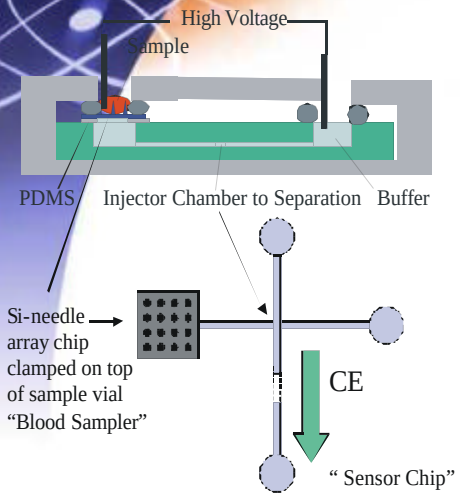


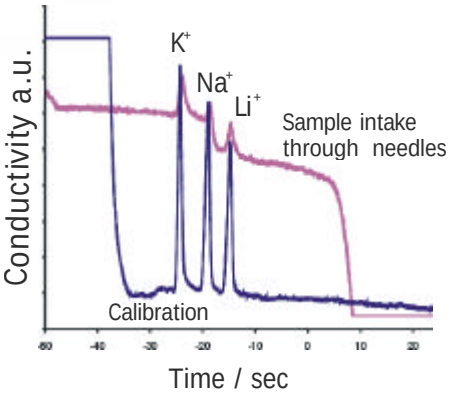


close-up of platinum electrodes integrated at end of electrophoresis microchannel

work of: Elwin Vrouwe and Regina Luttge

Silicon microneedles + CE chip



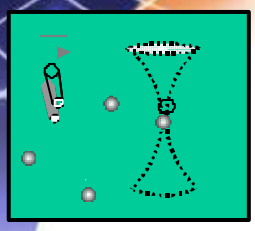


Work of: Regina Luttge

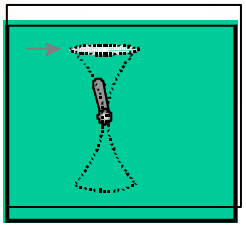
Buried microchannels in silicon

SEE PRESENTATION PART 1

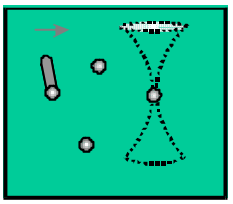
Mechanical measurements on DNA



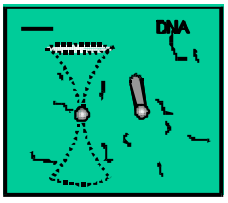
Capture bead



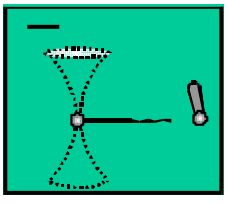
Place bead on pipette



Capture bead



Capture DNA



Stretch DNA

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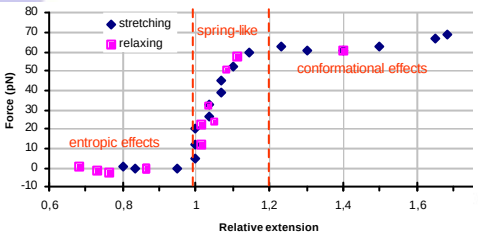
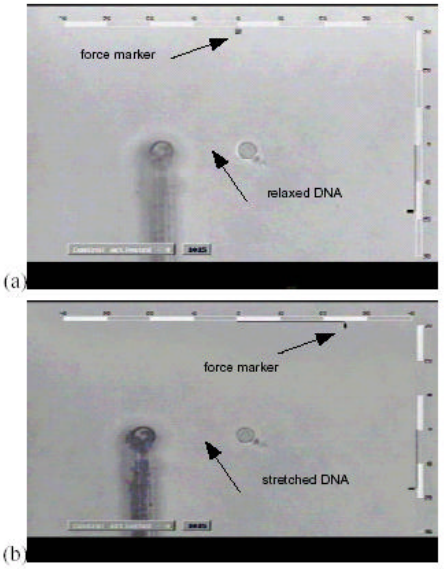
Stretching of ?-phage DNA

Two beads, one gripped by a micromachined pipette and the other by optical tweezers, with a DNA molecule (not observable) in between

(a) no force applied

(b) 30pN force applied



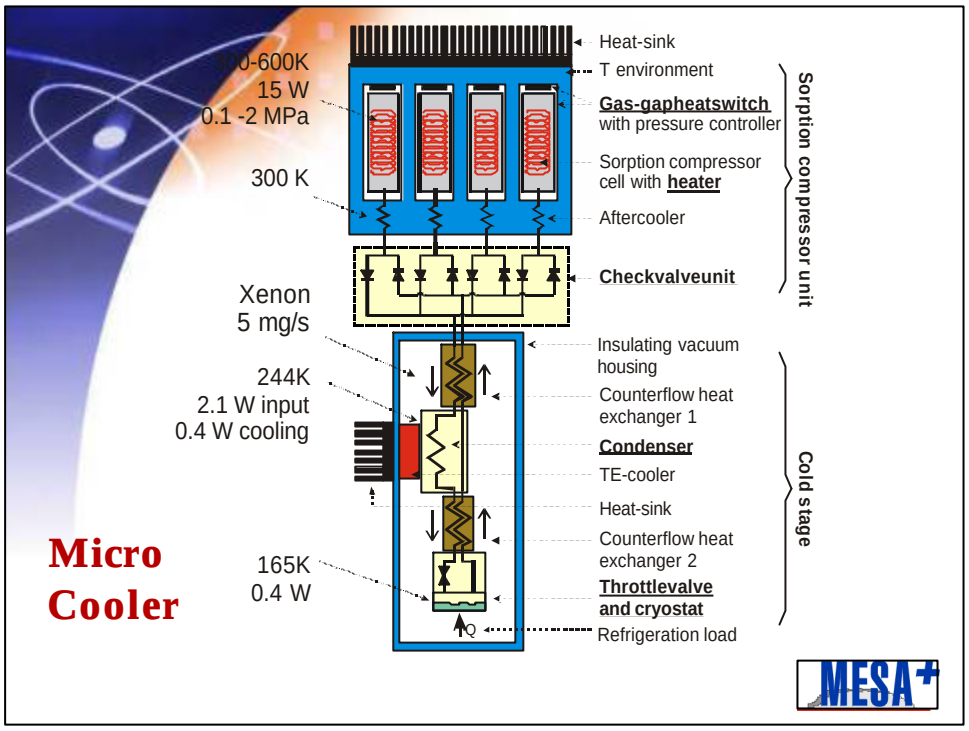


Miniaturized cryocooler

Johannes Burger, Han van Egmond, Harry Holland, Han Gardeniers, Marcel ter Brake and Miko Elwenspoek

MESA⁺ Research Institute, University of Twente, The Netherlands

Financial support:
Dutch Foundation for Technological Research (STW)
Project TTN.3100 "Microcooling"


Micro Cooler
300-600K
15 W
0.1 -2 MPa
300 K
Xenon
5 mg/s
244K
2.1 W input
0.4 W cooling
165K
0.4 W
Q
Heat-sink
T environment
Gas-gapheatswitch
with pressure controller
Sorption compressor
cell with heater
Aftercooler
Checkvalveunit
Sorption compressor unit
Insulating vacuum
housing
Counterflow heat
exchanger 1
Condenser
TE-cooler
Heat-sink
Counterflow heat
exchanger 2
Throttlevalve
and cryostat
Refrigeration load
Cold stage
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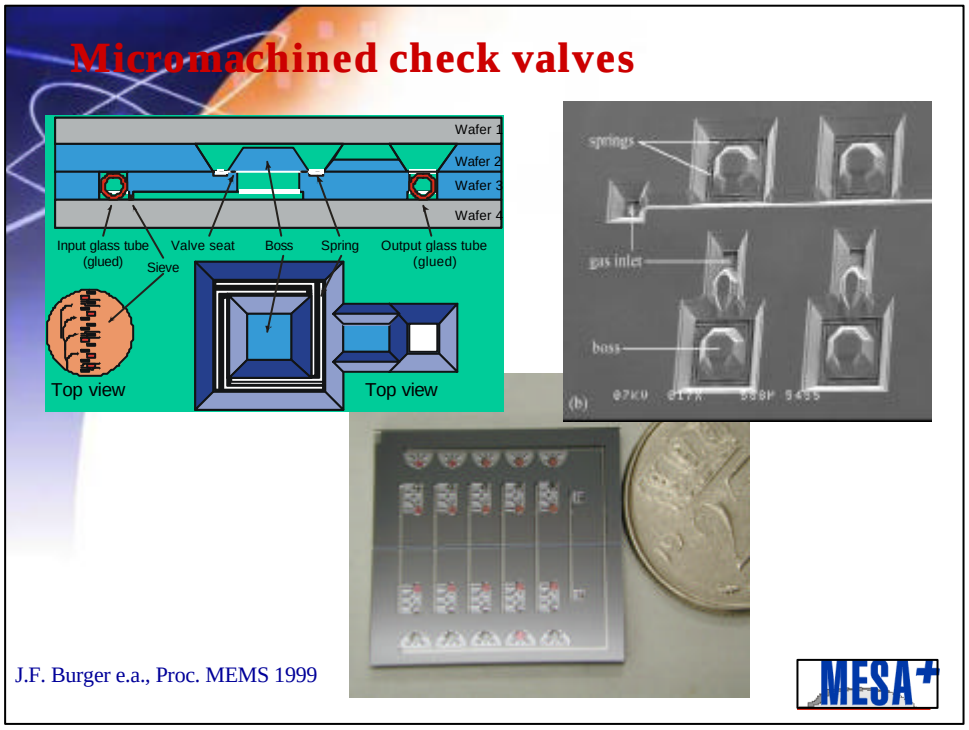
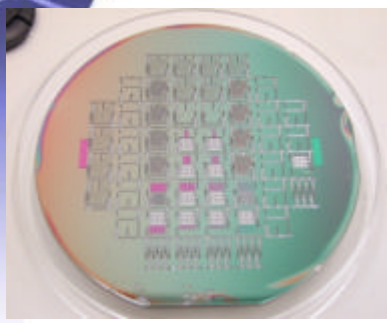
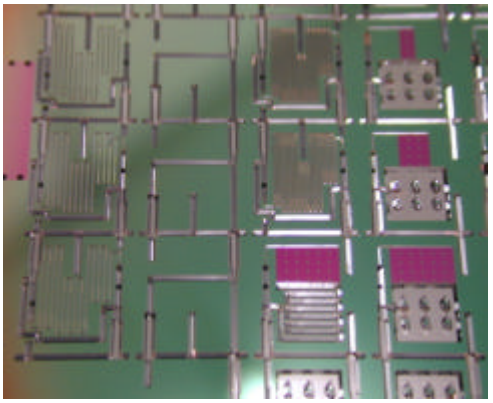

Micromachined check valves
Wafer 1
Wafer 2
Wafer 3
Wafer 4
Input glass tube
(glued)
Sieve
Valve seat
Boss
Spring
Output glass tube
(glued)
Top view
Top view
springs
gas inlet
boss
J.F. Burger e.a., Proc. MEMS 1999
MESA+

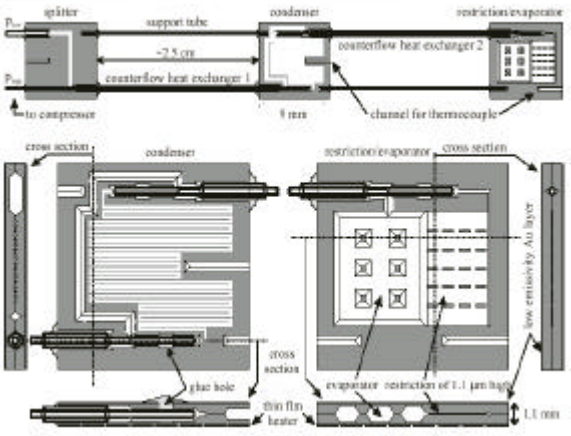
Cold stage structures on 4-inch silicon wafer



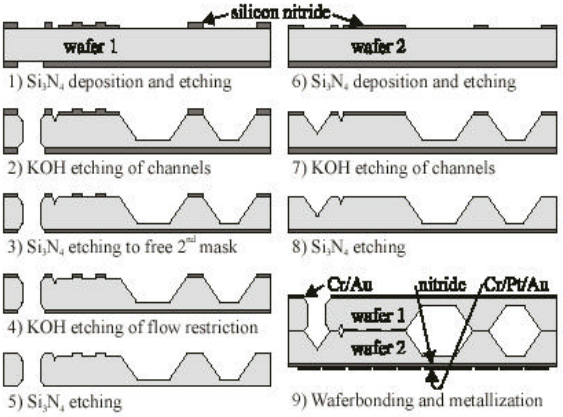


J.F. Burger e.a., Proc. MEMS 2001

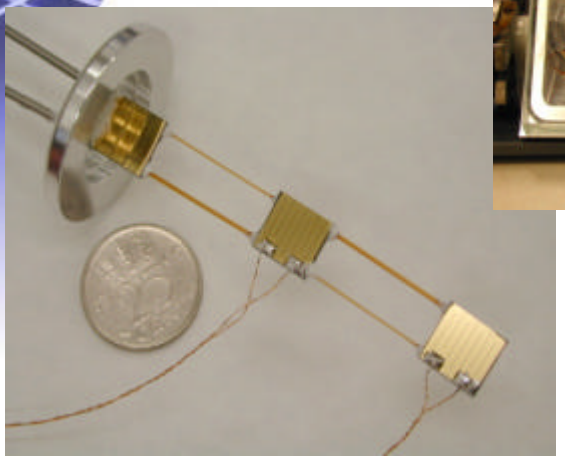
Micro cold stage

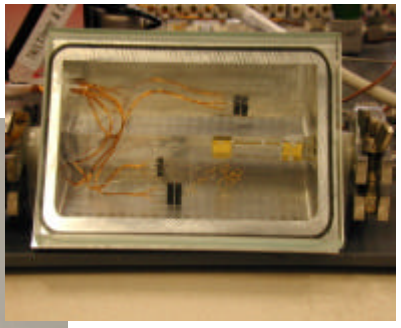


Micro cold stage fabrication



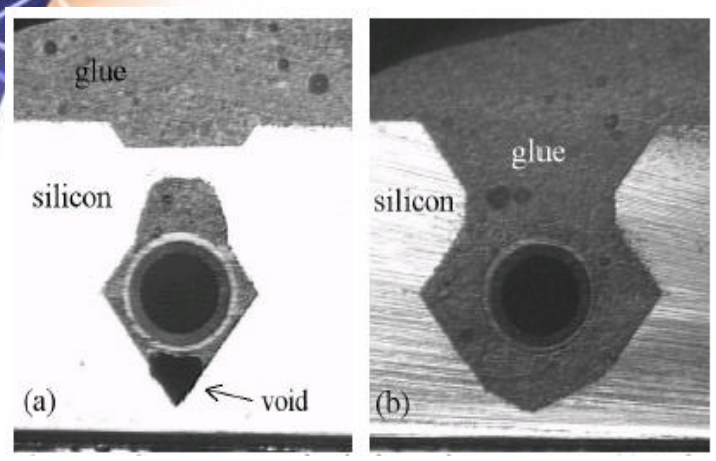
Integrated cold stage



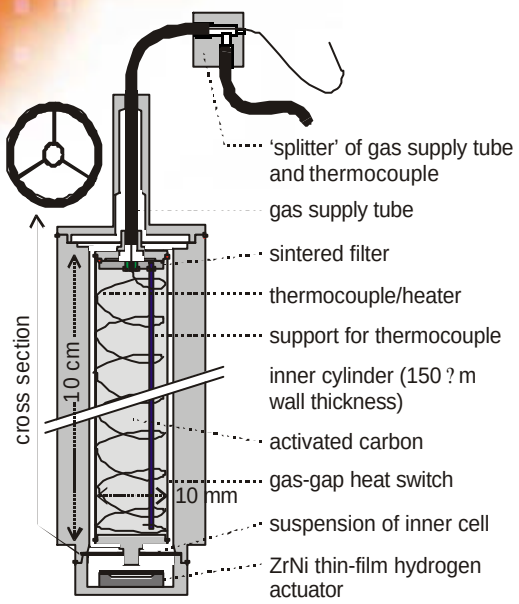


J.F. Burger e.a.,
MEMS 2001

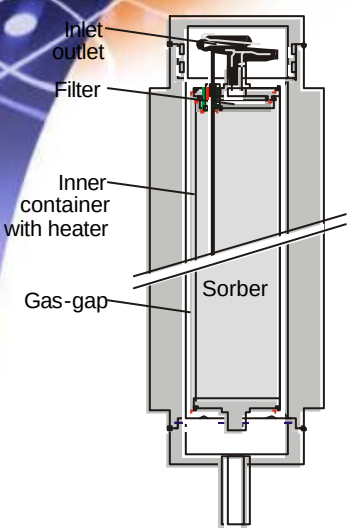
Glued capillary-to-chip connection

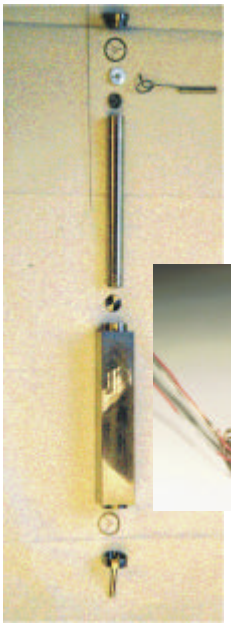


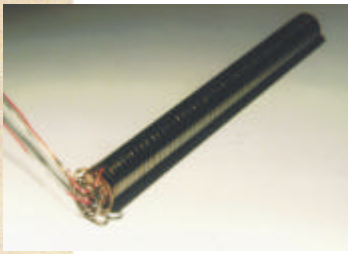
Compressor design



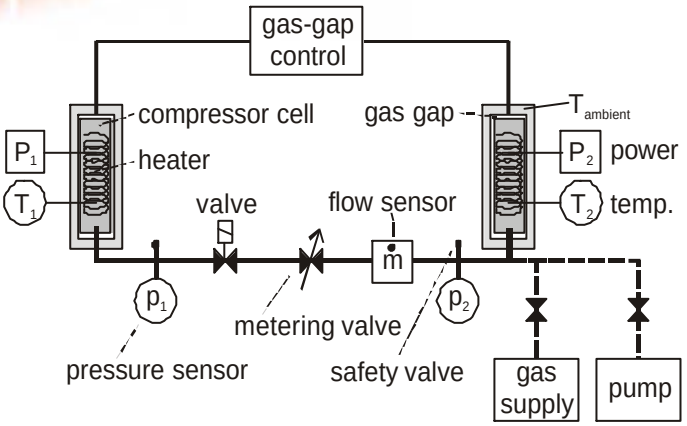
Sorber cell



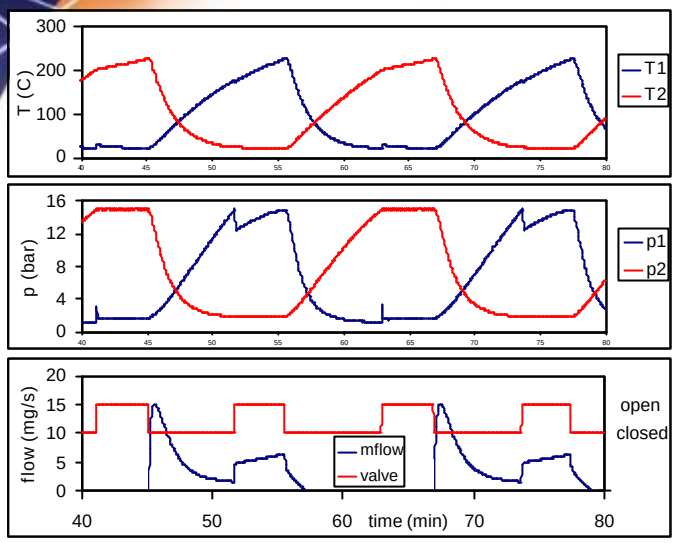




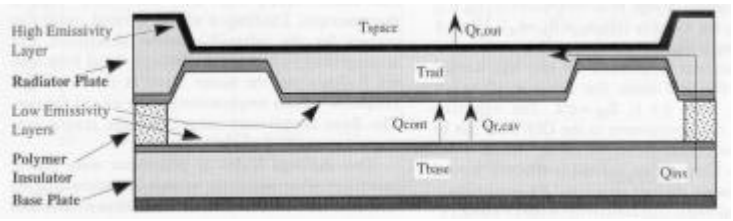
Compressor test set-up



Compressor flow test

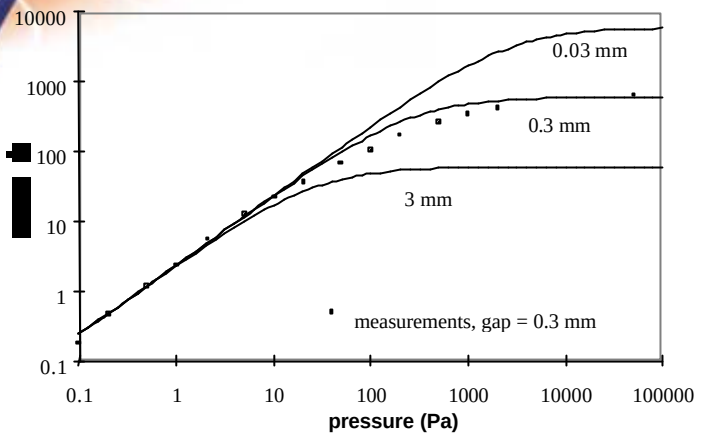


Thermal switches: mechanical example



T. Slater e.a. Techn. Digest Transducers 95, Stockholm

Gas gap heat switch with hydrogen (1)



J.F. Burger e.a., Thermodynamic considerations on a microminiature sorption cooler, Cryocoolers 10, Kluwer Academic / Plenum Press, New York, 1999, p. 553

Gas gap heat switch with hydrogen (2)

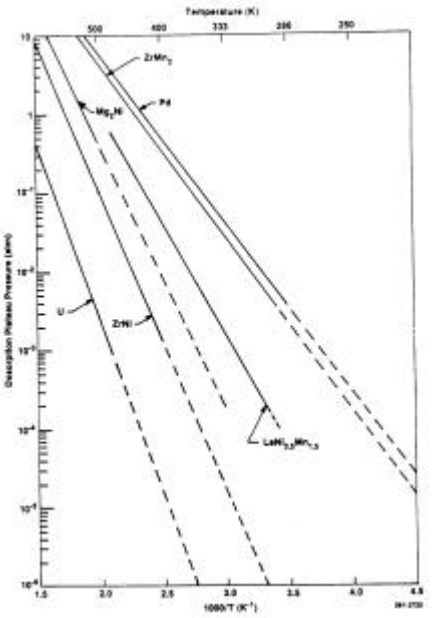
Requirements heat switch:

- low pressure < 0.5 Pa
- ON-OFF pressure ratio > 50*
- switching times < 30 sec
- actuation power < 0.2 W
- lifetime > 10^6 cycles

*limiting ON-OFF ratio ? 150 (mm) / gap width = 500 for gap of 300 ?m

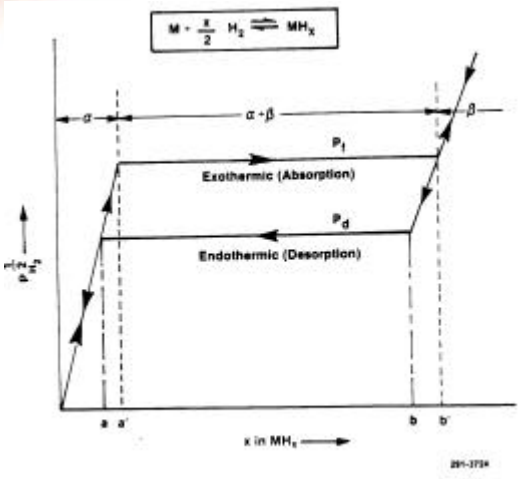
J.F. Burger e.a., Thermodynamic considerations on a microminiature sorption cooler, Cryocoolers 10, Kluwer Academic / Plenum Press, New York, 1999, p. 553

Metal hydrides



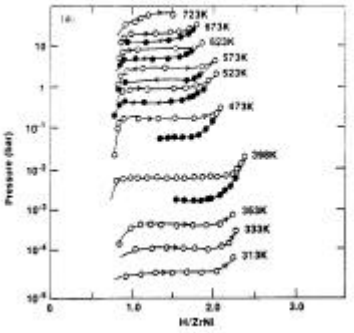
Van ‘t Hoff plots for
several metal hydrides

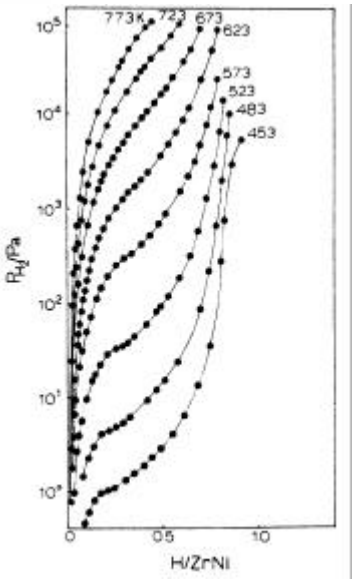
Metal hydrides: phase transition



Absorption and desorption lines for one isotherm

ZrNi-H



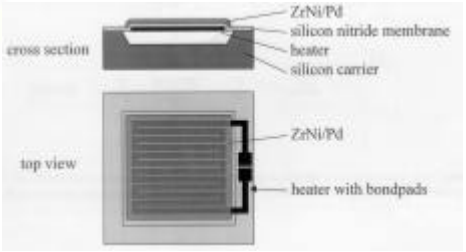


Experimental data for the ? ? ? and ? ?? phase changes of ZrNi-H
W. Luo e.a., J. Less-Common Metals 162, 1990, p.251

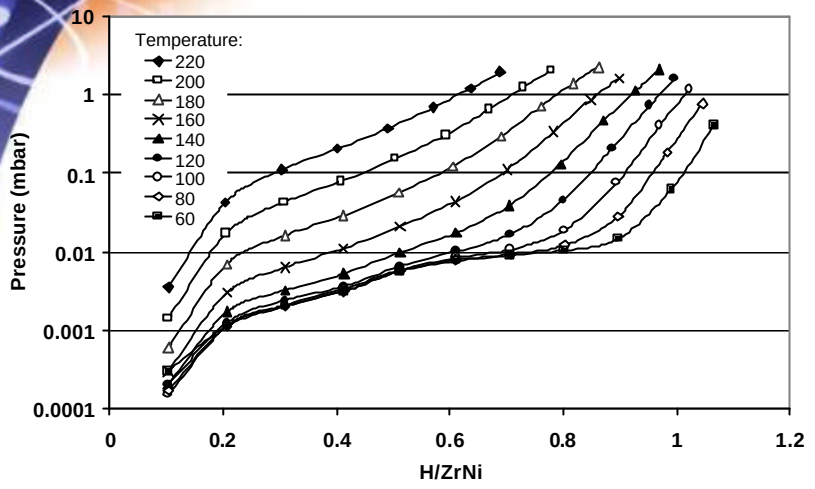
ZrNi films for reversible H_2 pressure actuation

Why films?

- Sputtered films offer possibilities for integration with e.g. heater elements
- Passivation with Pd film possible (bulk ZrNi is very sensitive to oxygen)
- Thin films offer faster hydrogen pressure switching

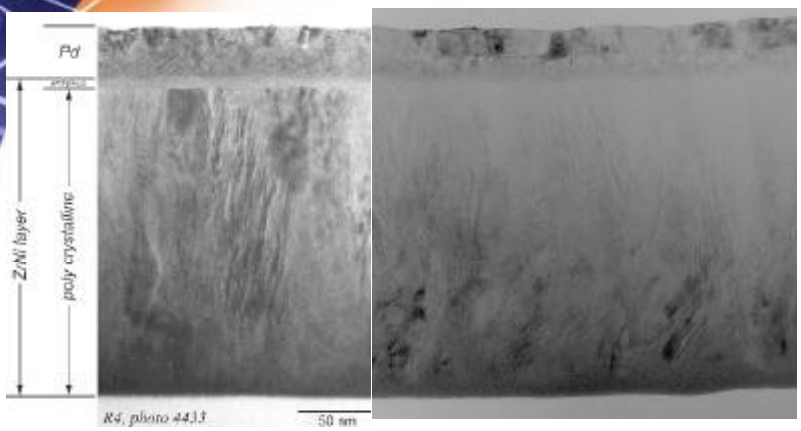


ZrNi films: Experimental results (1)



Gardeniers e.a., Proc. AKTUATOR 2000

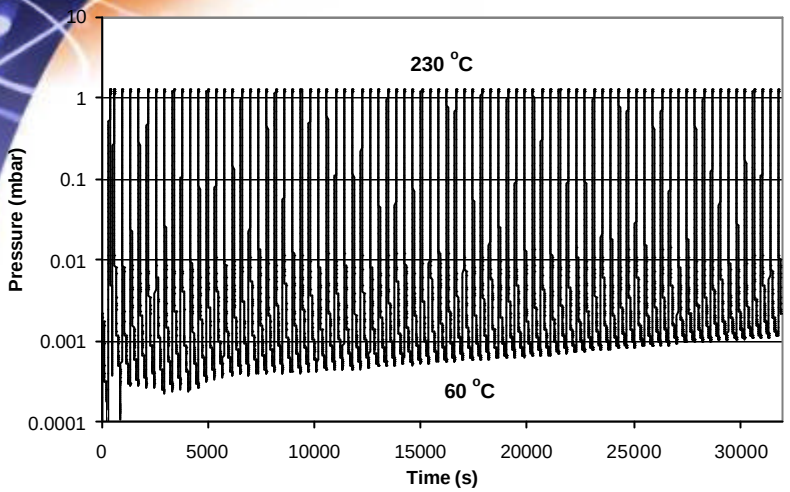
ZrNi films: Experimental results (2)



TEM pictures of ZrNi-Pd film before (left) and after (right) several thousands of absorption cycles

Gardeniers e.a., Proc. AKTUATOR 2000

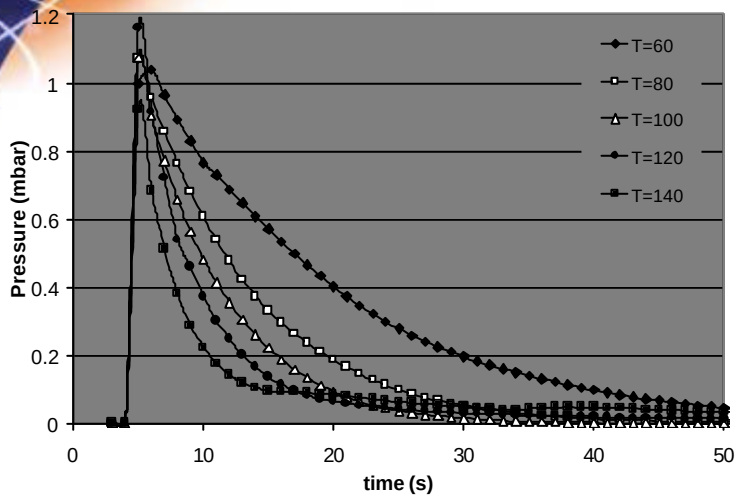
ZrNi films: Experimental results (3)



Obtained pressure swing: 0.03 Pa - 125 Pa

Gardeniers e.a., Proc. AKTUATOR 2000

ZrNi films: Experimental results (4)



Obtained switching times: less than 60 secs.

Gardeniers e.a., Proc. AKTUATOR 2000

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