Micromachining of microchannels in silicon

for cryogenic cooling purposes

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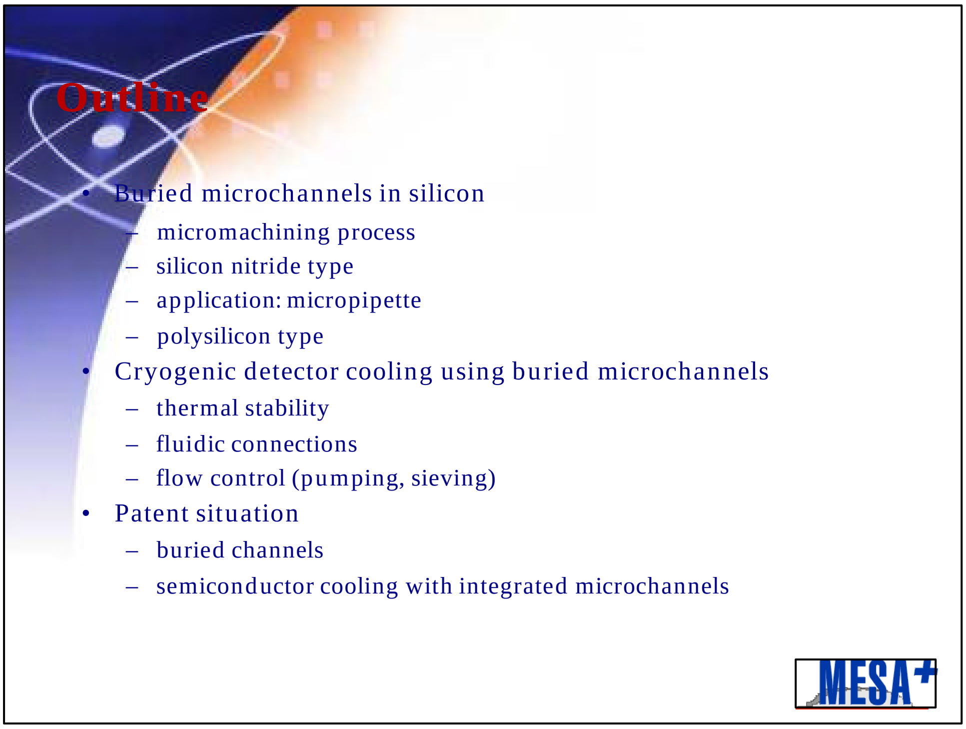
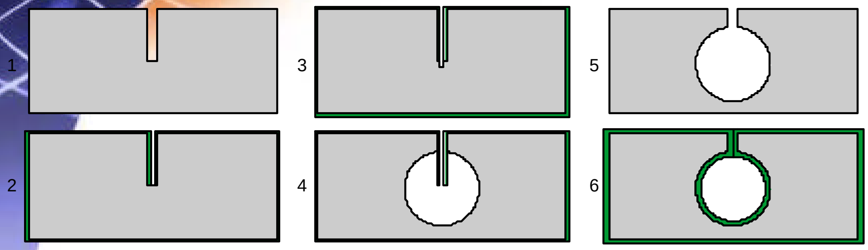


Outline

- Buried microchannels in silicon
  - micromachining process
  - silicon nitride type
  - application: micropipette
  - polysilicon type
- Cryogenic detector cooling using buried microchannels
  - thermal stability
  - fluidic connections
  - flow control (pumping, sieving)
- Patent situation
  - buried channels
  - semiconductor cooling with integrated microchannels

Microchannels buried in a silicon wafer

Burried channel process



See: animation of buried channel process
(courtesy of Oxford Instruments)

http://www.oxfordplasma.de/process/si_sinch.htm

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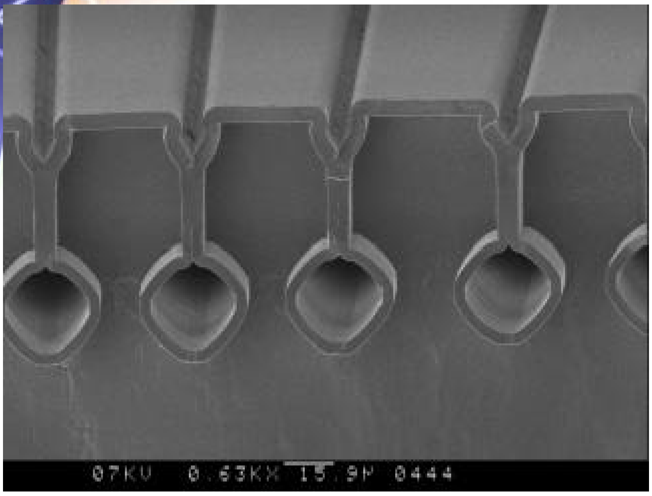
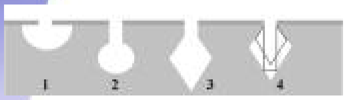
Silicon nitride type

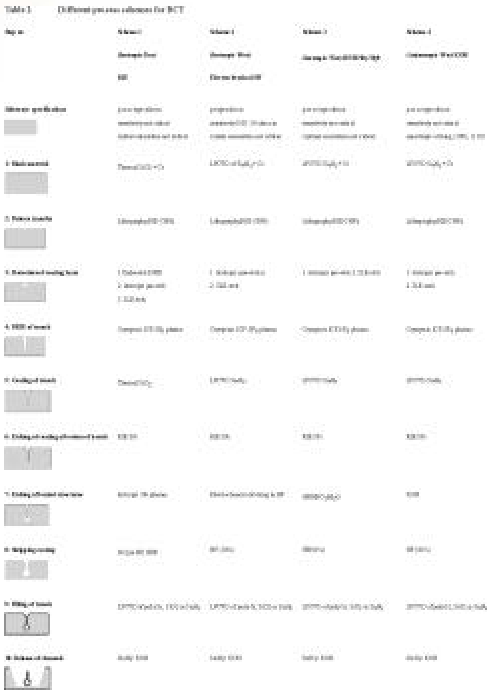


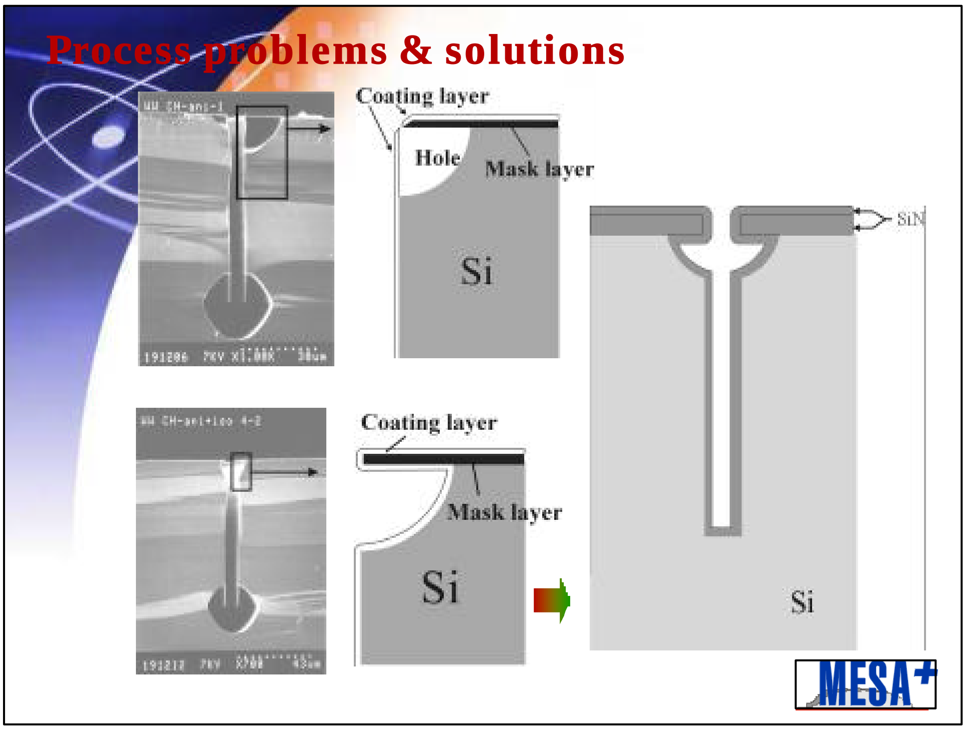


Different profiles of buried channels

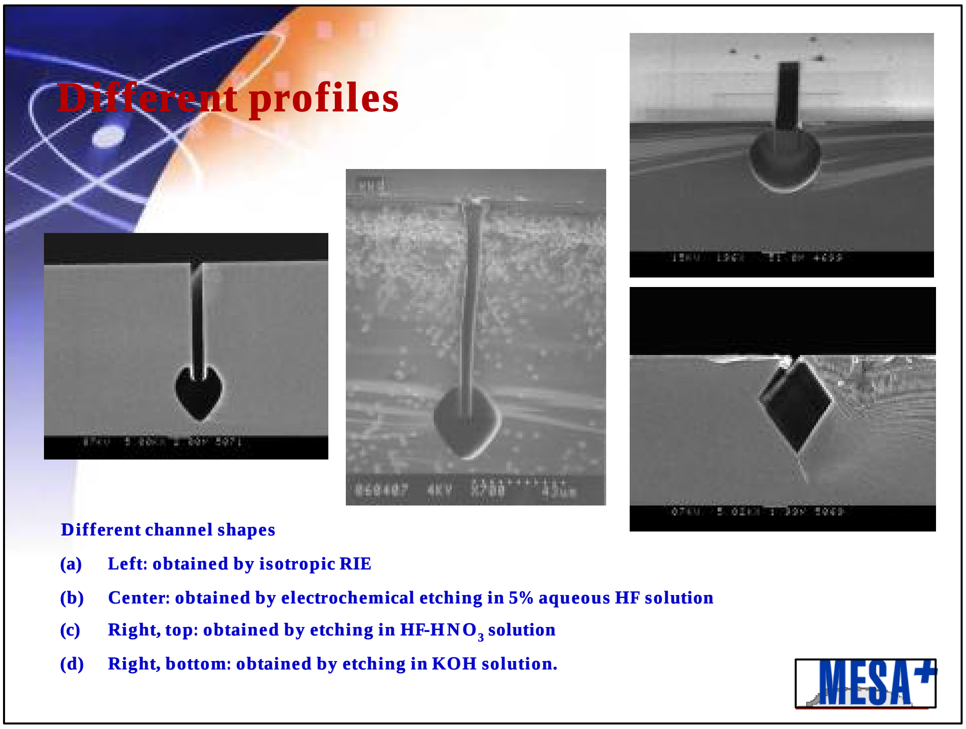
M.J. de Boer et al.

J. MEMS 9, 2000, pp. 94-102





Process problems & solutions

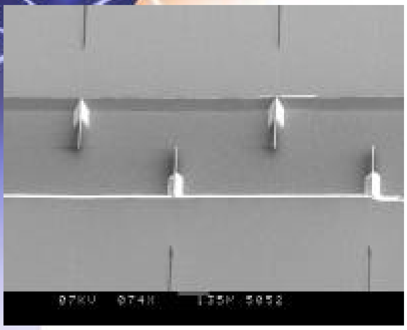


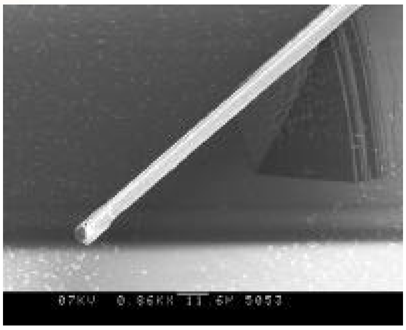
Different profiles

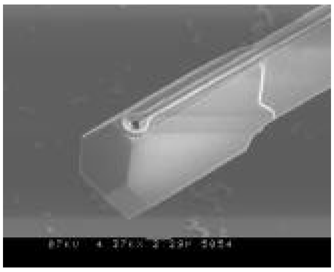
Different channel shapes

- **(a) Left: obtained by isotropic RIE**
- **(b) Center: obtained by electrochemical etching in 5% aqueous HF solution**
- **(c) Right, top: obtained by etching in HF-HNO_3 solution**
- **(d) Right, bottom: obtained by etching in KOH solution.**

Micropipettes for DNA studies

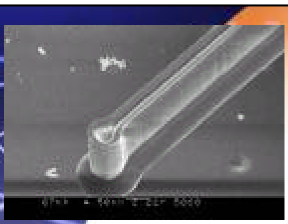


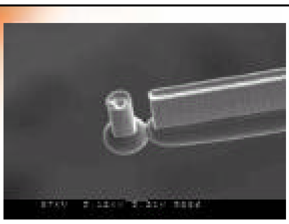


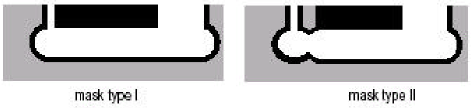


C. Rusu et al.,

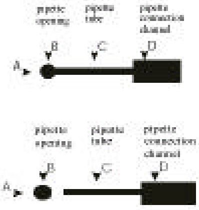
J. MEMS 10, 2001, pp. 238-246







mask type I *mask type II*



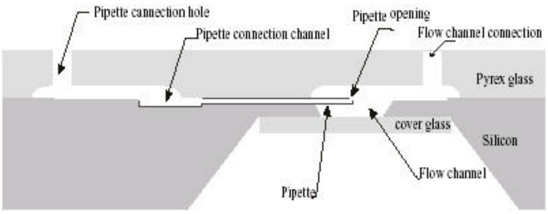
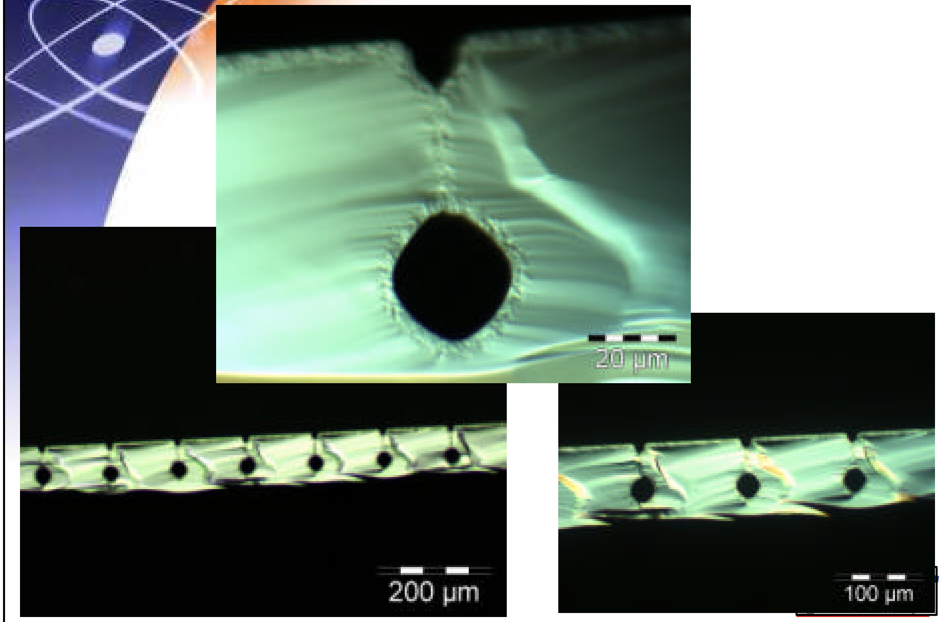
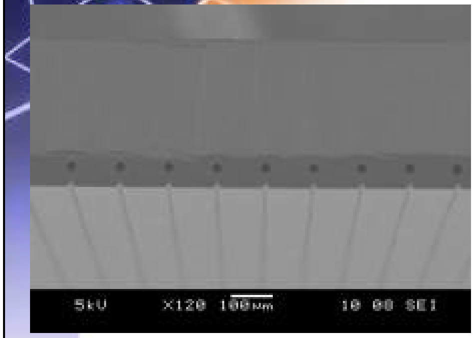


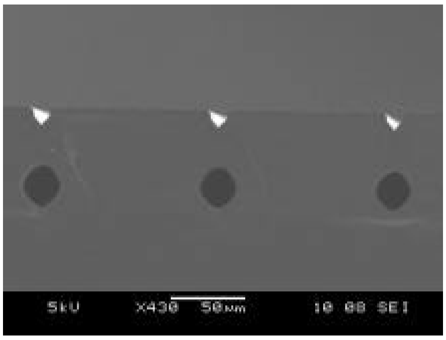
Fig. 3. Cross section of a flow cell consisting of integrated micropipette in a flow channel.

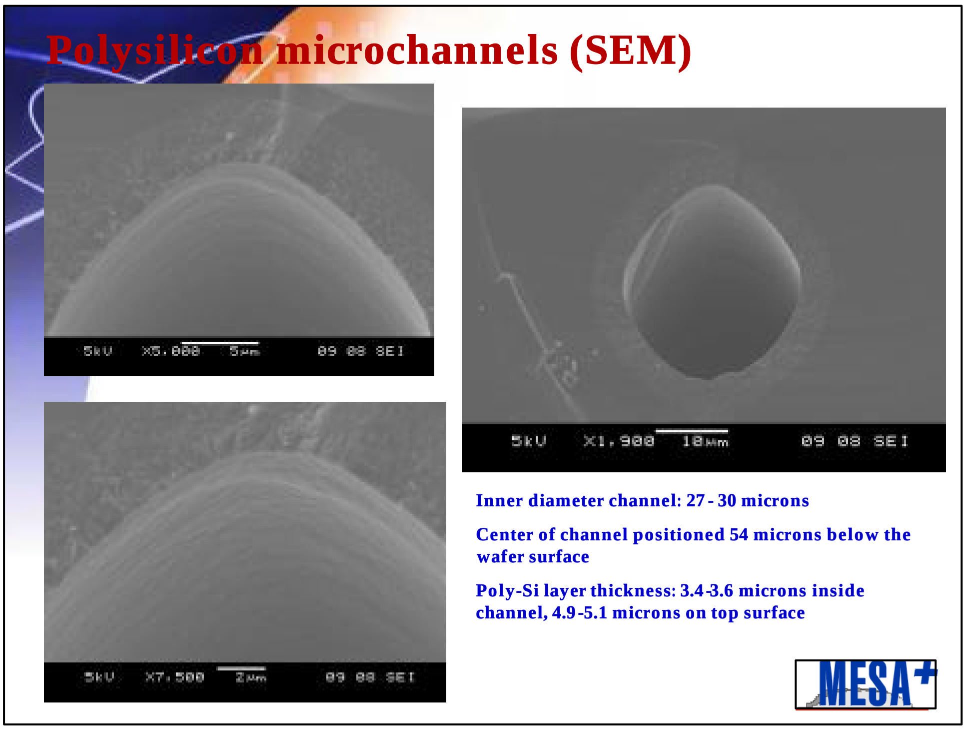
Polysilicon microchannels (opt. microsc.)



Polysilicon microchannels (SEM)







Polysilicon microchannels (SEM)

Inner diameter channel: 27 - 30 microns

Center of channel positioned 54 microns below the wafer surface

Poly-Si layer thickness: 3.4-3.6 microns inside channel, 4.9-5.1 microns on top surface

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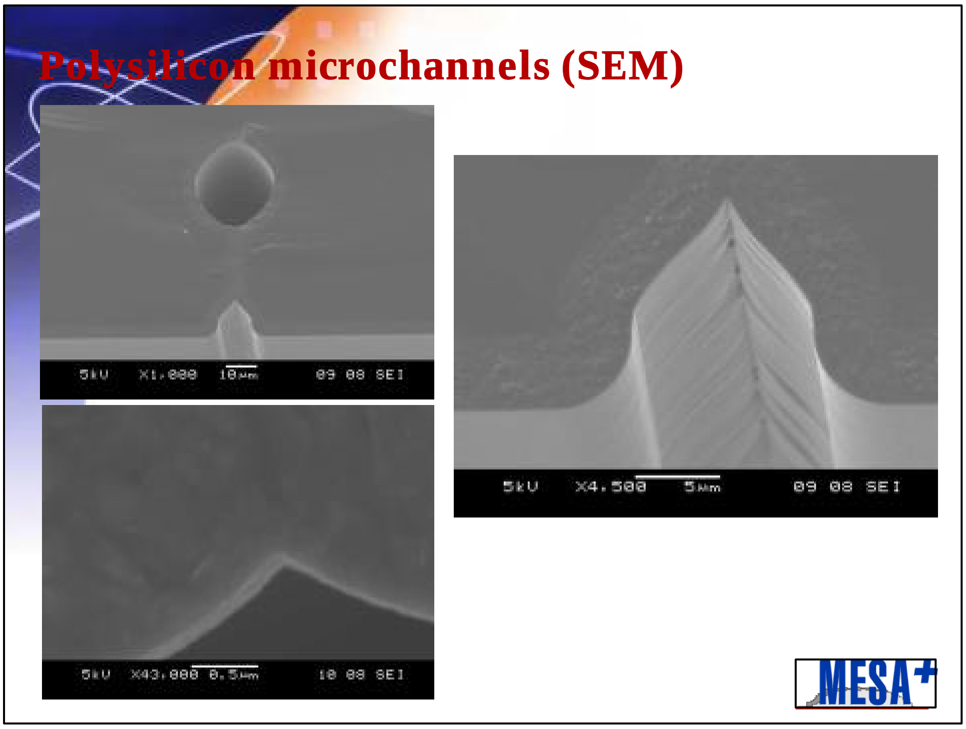
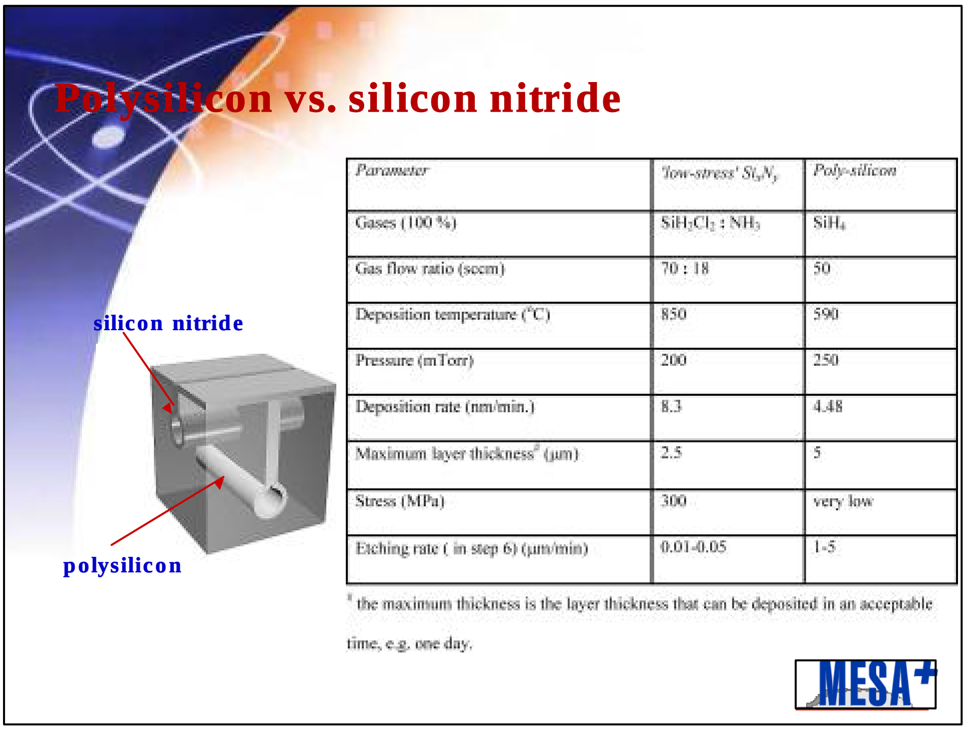


Polysilicon microchannels (SEM)



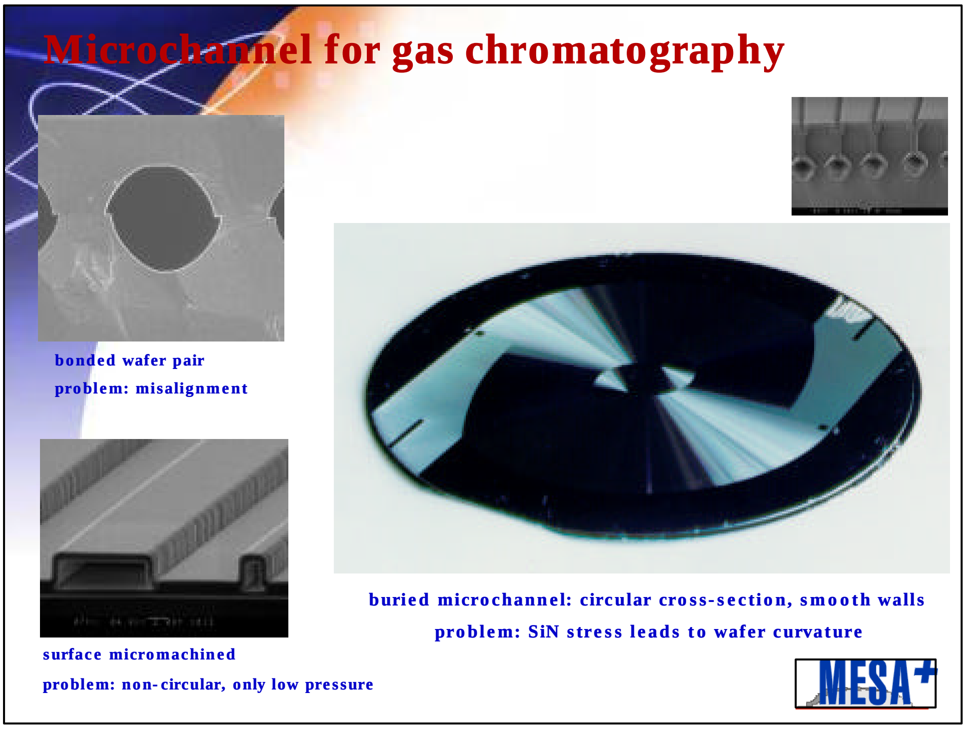
Polysilicon vs. silicon nitride

silicon nitride

polysilicon

Parameter	*'low-stress' Si_xN_y*	*Poly-silicon*
Gases (100 %)	$SiH_2Cl_2 : NH_3$	SiH_4
Gas flow ratio (sccm)	70 : 18	50
Deposition temperature (°C)	850	590
Pressure (mTorr)	200	250
Deposition rate (nm/min.)	8.3	4.48
Maximum layer thickness[#] (µm)	2.5	5
Stress (MPa)	300	very low
Etching rate (in step 6) (µm/min)	0.01-0.05	1-5

[#] the maximum thickness is the layer thickness that can be deposited in an acceptable time, e.g. one day.



Microchannel for gas chromatography

bonded wafer pair
problem: misalignment

surface micromachined
problem: non-circular, only low pressure

buried microchannel: circular cross-section, smooth walls
problem: SiN stress leads to wafer curvature

Cryogenic cooling of silicon detectors using buried microchannels?

Thermal stability

- residual stresses: silicon nitride / polysilicon
- thermal expansion coefficients
  - polysilicon: basically the same as Si X-tal:

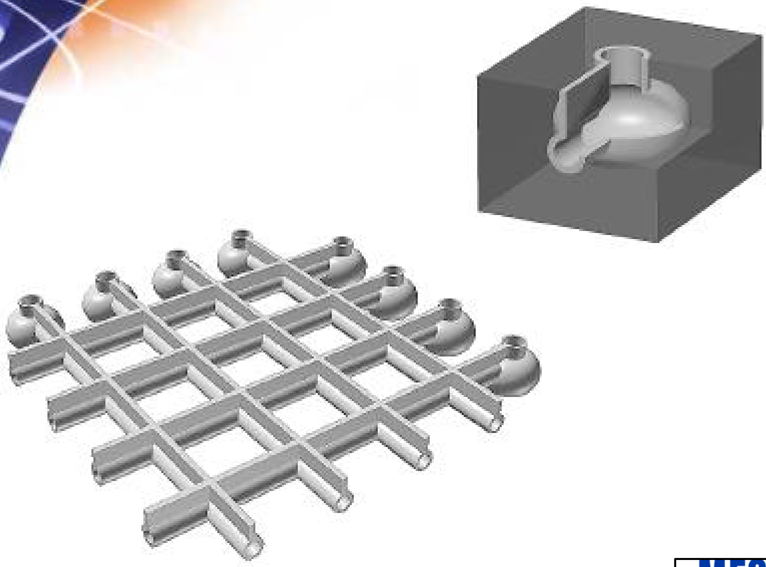
Temperature (K)	100	200	400	1000
Lin.Coeff. Therm. Exp. (10^{-6}/K)	0.5	1.1	2.7	4.7

  - LPCVD silicon nitride: 2.3 (stoichiom.) - 4 (Si-rich) 10^{-6} /K
- annealing of polysilicon on Si: gives "epitaxial" regrowth

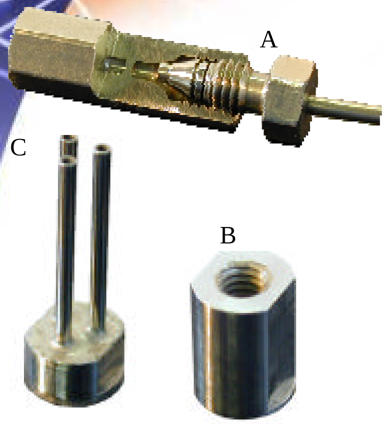
Fluidic connections and integration of components

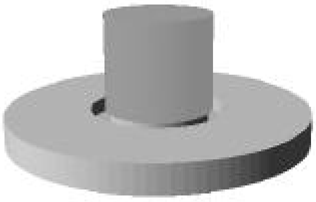
Some examples

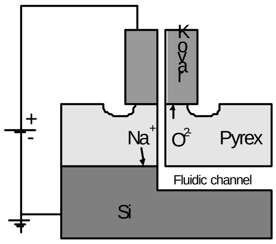
Buried channels with etched inlet



Local (anodic) bonding of Kovar to Pyrex

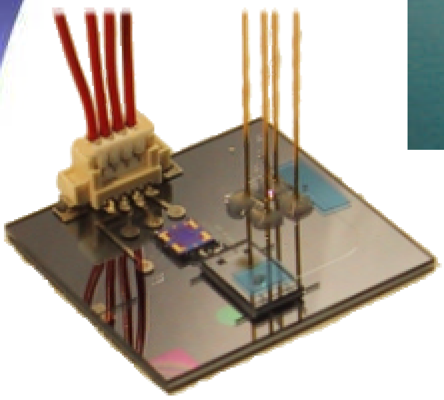


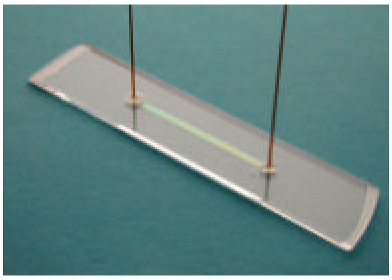




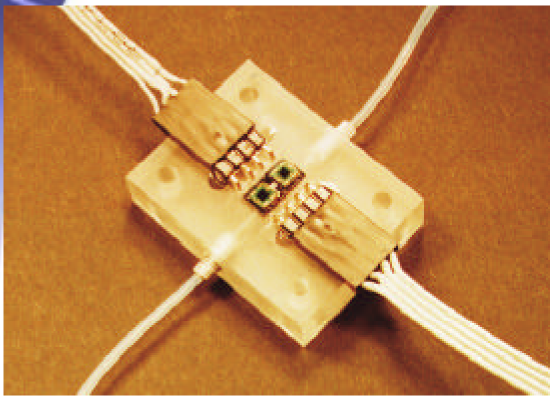
M.T. Blom et al., J. Micromech. Microeng. 11 (2001) 382

Glued capillaries?

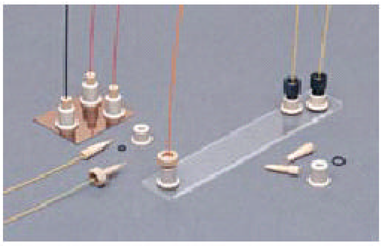


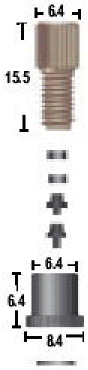


Connections in PMMA block



UpChurch Nanoports





Ways of integration

Modular

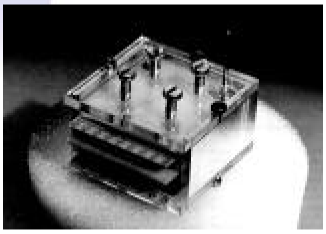
- Flexible component design
- Small series
- Standard pick&place
- Mixed technology

- Interconnections

Monolithic

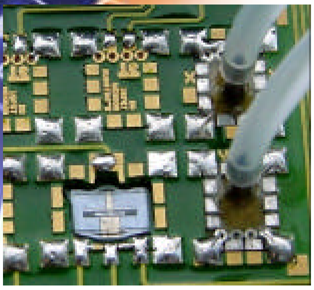
- Small dead volumes
- Suited for large(r) series

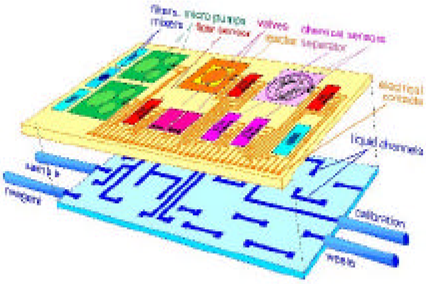
- Design constraints
- Decreasing yield with nb. components

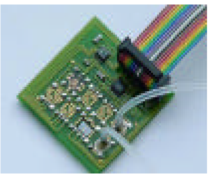


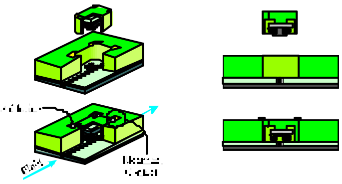
Vertical stacking
Institute of Microtechnology (IMT)
University of Neuchâtel, Switzerland

Modular Assembly TAS



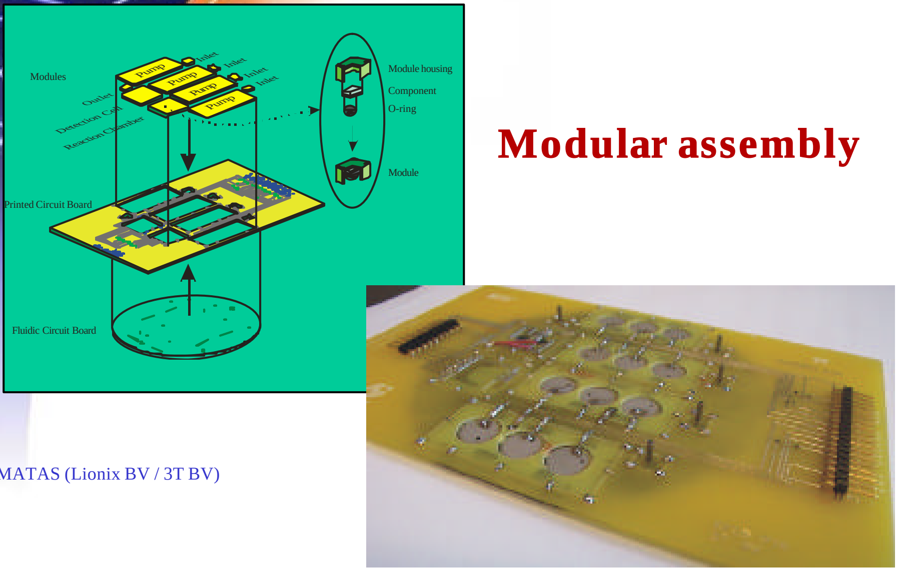






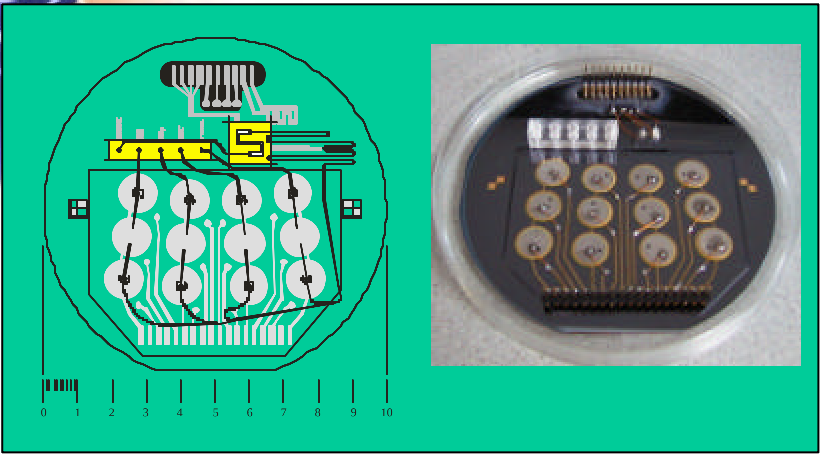
"MATAS" by Lionix B.V. (formerly 3T BV), Enschede, NL

Modular assembly



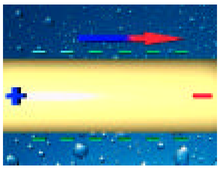
MATAS (Lionix BV / 3T BV)

Monolithic design

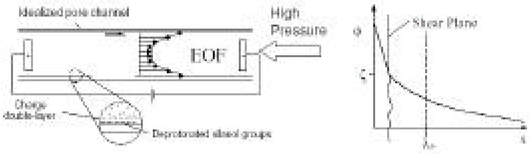


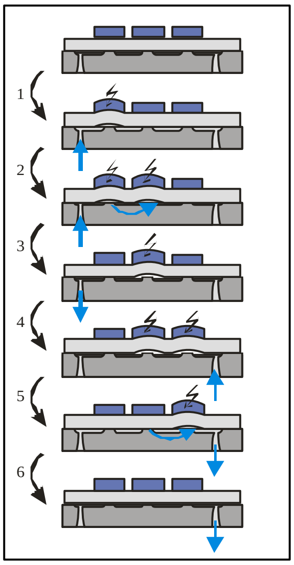
Fluidic control

- micropumps
  - piezoelectrically driven?
  - EOF (elektrokinetic)?



Working Principles of EK Pumps





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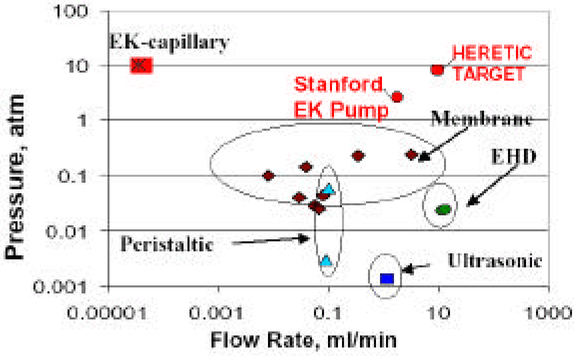
Micropump Technology Overview



S. Shoji and M. Esashi, J. Micromech. Microeng 4, 157, 1994.
P. Gravesen, J. Branebjerg and O. S. Jensen, J. Micromech. Microeng 3, 168, 1993.

from: *DARPA HERETIC Program*

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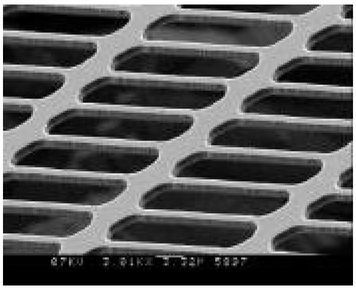
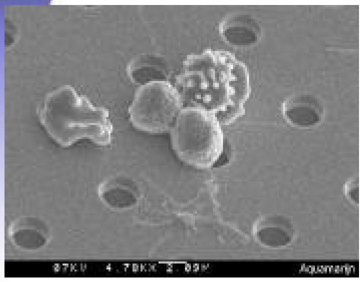
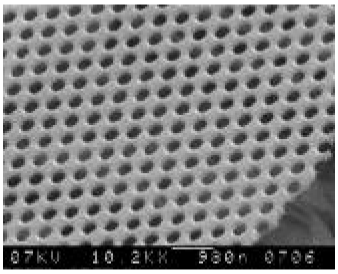
Micromachined filters?







Source: Aquamarijn Micro Filtration , The Netherlands

Patent situation

US 4993143 D.W. Sidner et al., Mar. 27, 1990:

Method of making a semiconductive structure useful as a pressure sensor

(describes process of making buried channels; sealing by lateral epitaxial silicon growth, to my knowledge oldest patent on this topic)

US 5210440 J.M. Long, Jun. 3, 1991:

Semiconductor chip cooling apparatus

(chip die on support surrounded by flowing cooling fluid)

US 6254214 A. Murthy et al., Jun. 11, 1999:

System for cooling and maintaining an inkjet print head at a constant temperature

(channels etched from both sides of wafer)

Two recent patents of ST Microelectronics:

EP 1043770 G. Barlocchi et al., Oct. 11, 2000 (priority Apr. 9, 1999):

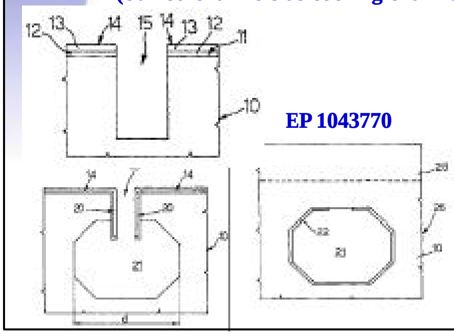
Formation of buried cavities in a monocrystalline semiconductor wafer

(sealing by lateral epitaxial silicon growth)

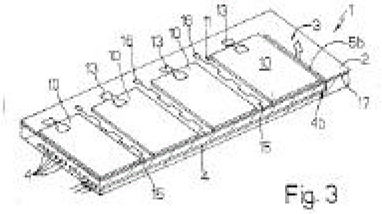
EP 1123739 U. Mastromatteo et al., Aug. 16, 2001 (priority Feb. 11, 2000):

Integrated device for microfluid thermoregulation , and manufacturing process thereof

(buried channels as cooling channels for PCR device)



EP 1043770



EP 1123739