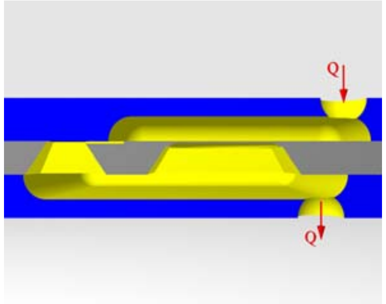
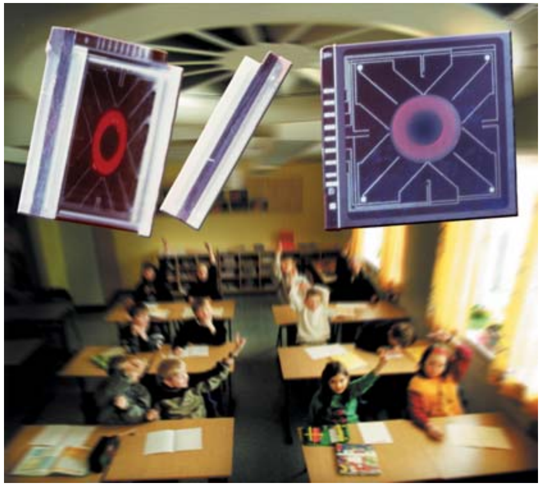
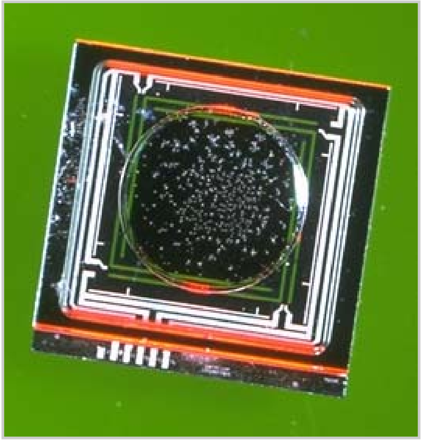
# Fys4230
# Micro- and nanosystems modeling and design

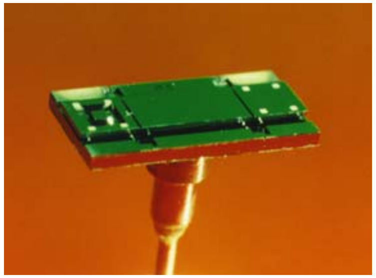
## Fall 2009

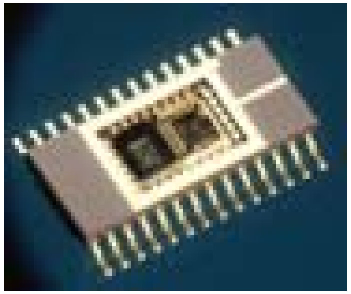
**Responsible: Liv Furuberg**
**SINTEF Information and communication technology**











# web page with all course information

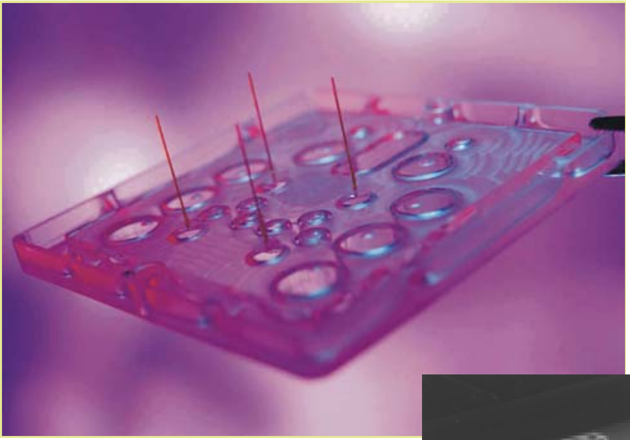
- http://www.uio.no/studier/emner/matnat/fys/FYS4230/h09/
- Lecture plan
- Messages, keep yourself updated!
- Powerpoint presentations from lectures
- Exercises
- 2 compulsory exercises, deadlines

- Book: Stephan D Senturia: “Microsystems Design”

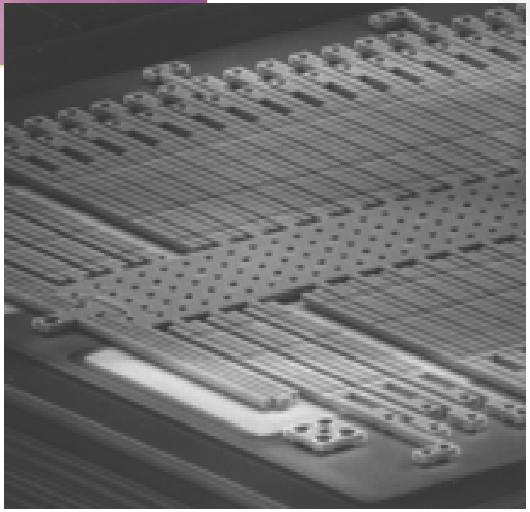
Kluwer academic publishers

# Main course contents + 4 “cases”:

1) Micro fabrication, materials
2) Design of lithographic masks
3) Physics governing behaviour of  microsystems
4) Modelling of microsystems behaviour

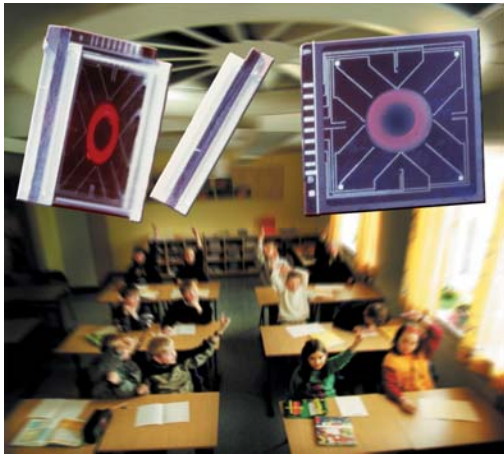


Lab-on-a-chip



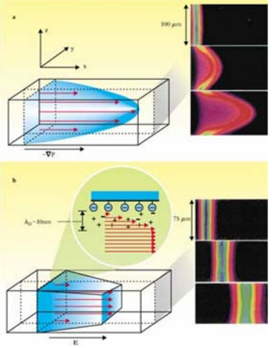
Accelerometer

Projector

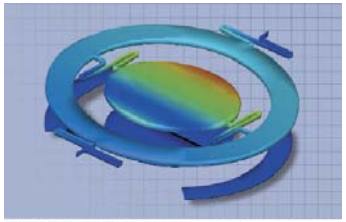


Pressure sensor

Fluid dynamics

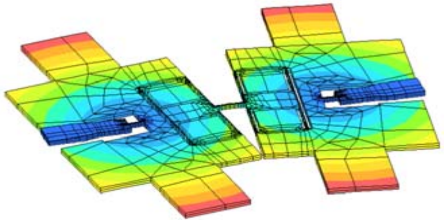


Multiphysics



*Analysis of a MEMS mirror illustrates the relative displacement of its components. You can also analyze modal frequency, residual stress, maximum stress, electrostatic force of electrodes, beam diffraction, and crosstalk between multiple mirrors in an array.*

Structural mechanics



Electronics

Signal processing

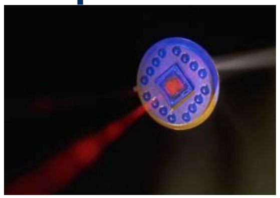
Electromagnetism

Chemistry

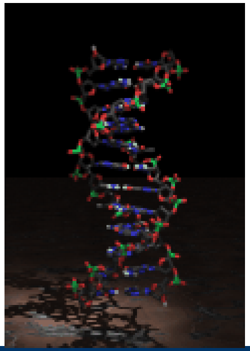
**Challenge:**

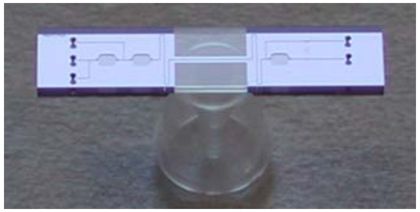
**Design functional elements that can be manufactured by microtechnology**

Optics



Biotechnology



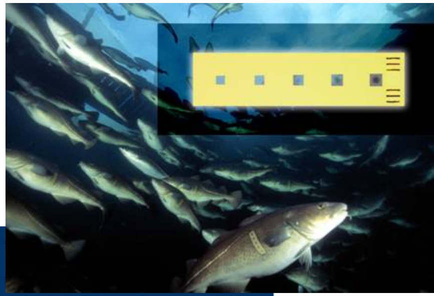


Capillary flow

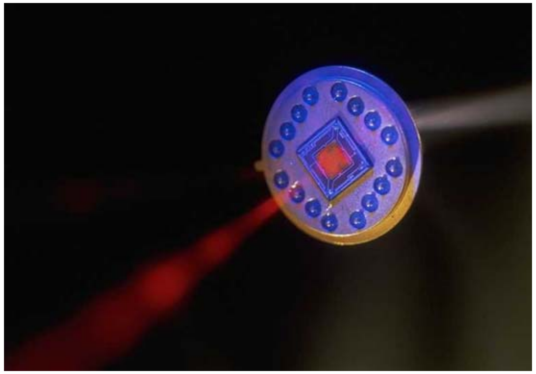
Surface physics

Functional thin films

Material science



- **MEMS (Micro-Electro-Mechanical Systems)**
- **Microsystems**
- **Microtechnology**



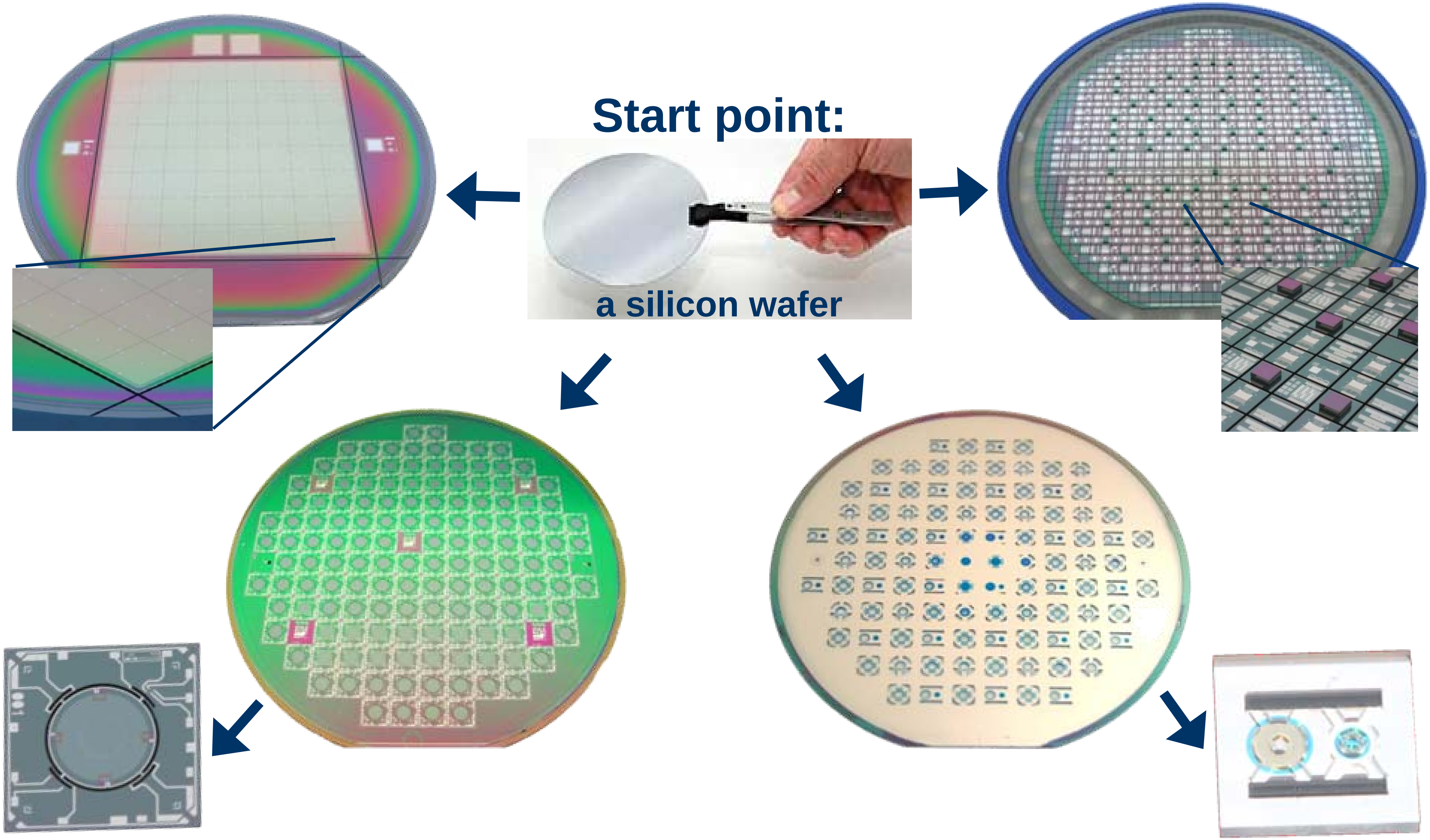
- Sensors and actuators
- The functional element is of micrometer scale
- Made from silicon, quartz or polymer
- Integrated with electronic circuits
- Produced using integrated circuit fabrication technologies

# MiNaLab (Micro- and Nanotechnology Laboratory in Oslo)




- Shared facility for the University of Oslo and SINTEF with two separate clean room floors:
  SINTEF: 800 $m^2$
  University of Oslo: 600 $m^2$
- SINTEF:
  - Silicon production line with annual capacity of 10.000 150 mm wafers
  - 100 mm and 150 mm wafers
  - Microenvironments with class 10
- The most advanced laboratory in Norway for micro- and nanotechnology
- Situated on the campus of University of Oslo
- 240 MNOK investment in scientific equipment and laboratory

# Processing in the lab

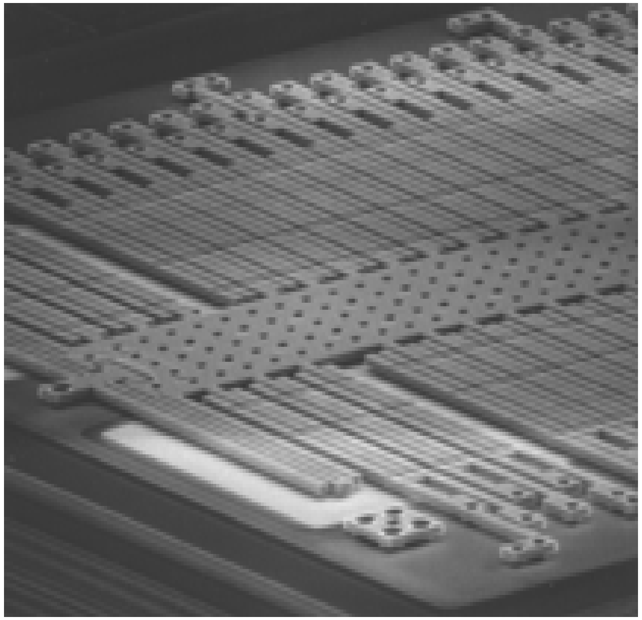


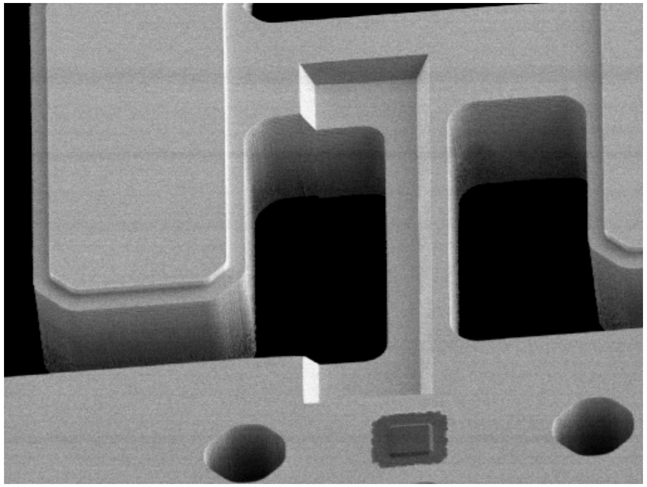
**Start point:**

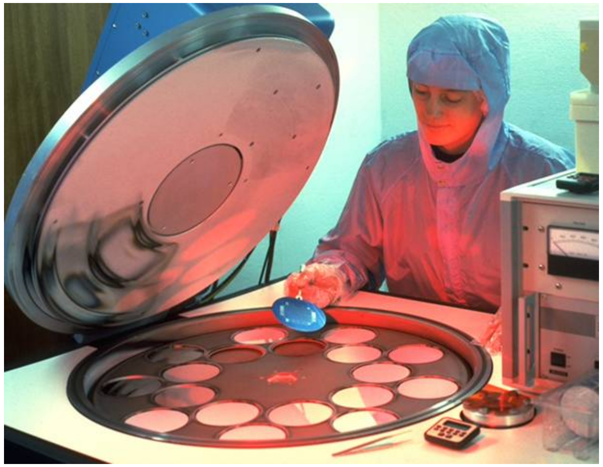
**a silicon wafer**

# Micromachining

- Top – down manufacturing
- 3D structures
- Lithography defines areas to be etched away
- Bonding of several wafers
- Thin films

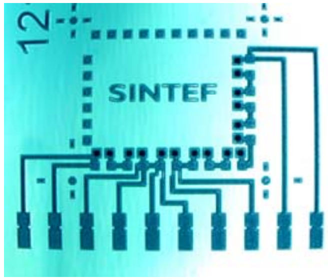


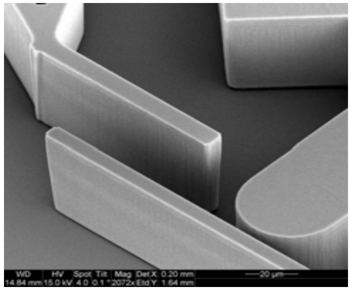


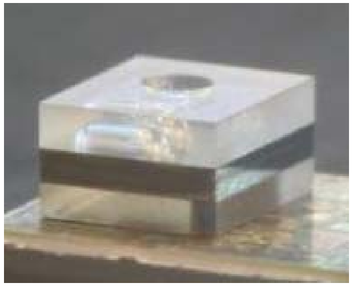


# Key processes in the clean room

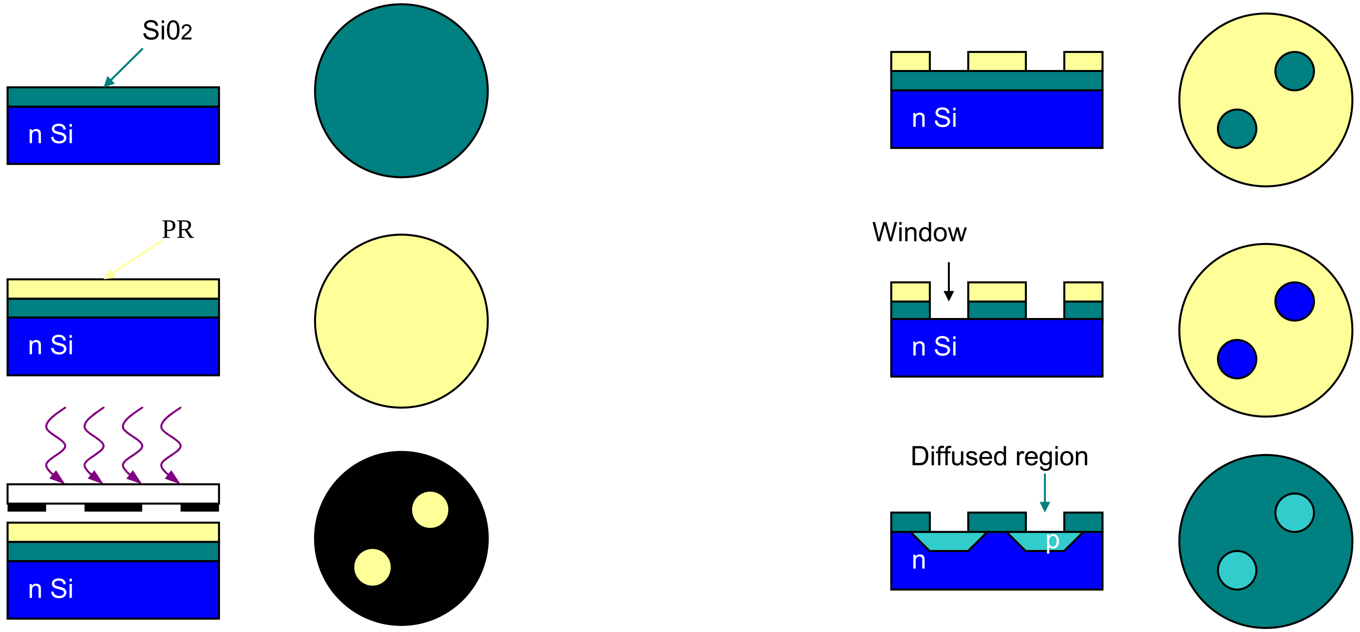
- High temperature processes in furnaces at 400 - 1200 °C
- Deposit various thin layers on the surface
- Etch thin layers
- Making patterns on the wafers
- Etch 3-dimensional structures in the silicon wafer
- Various characterization equipment
- Bond wafers to form a stack





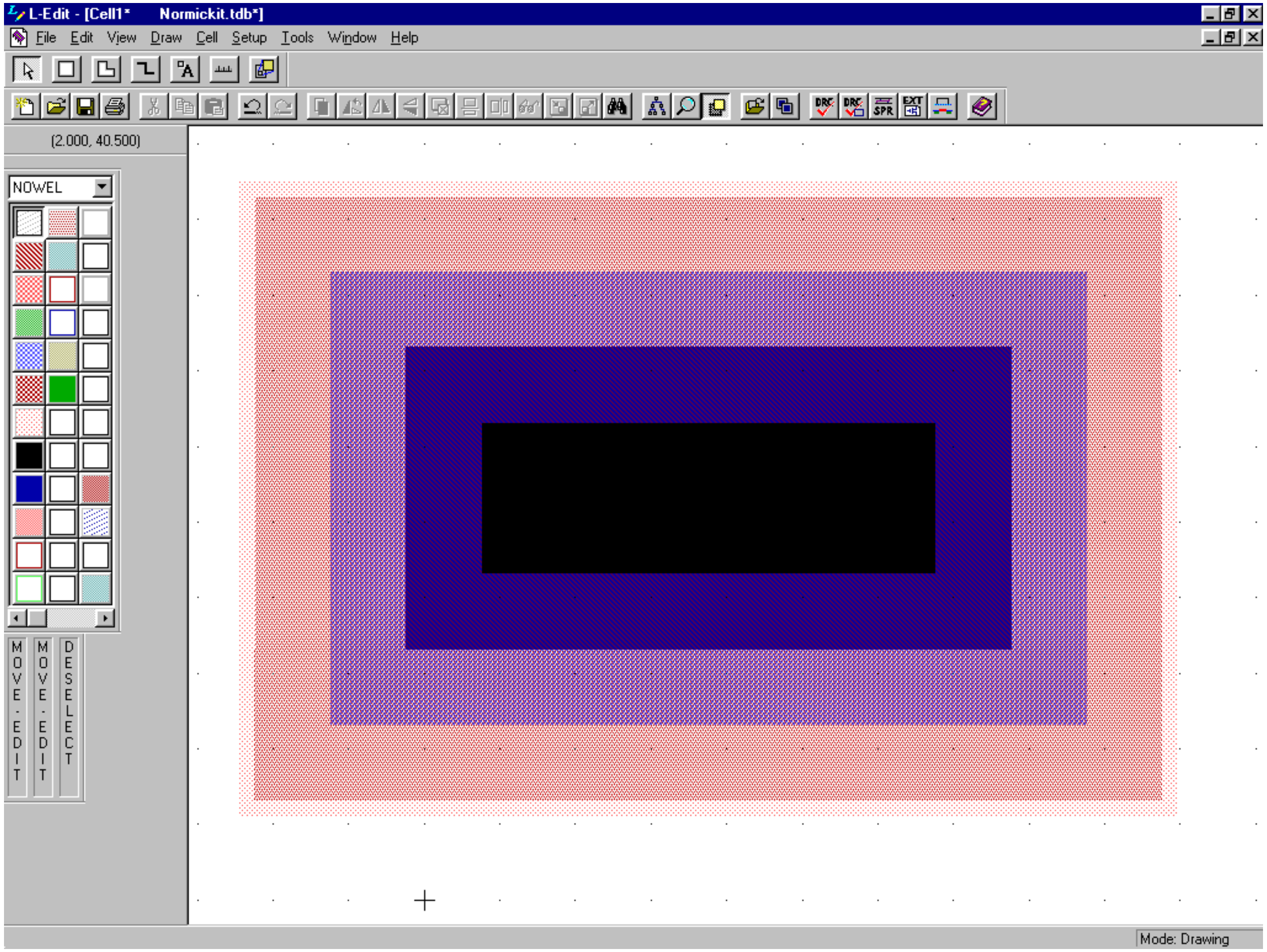


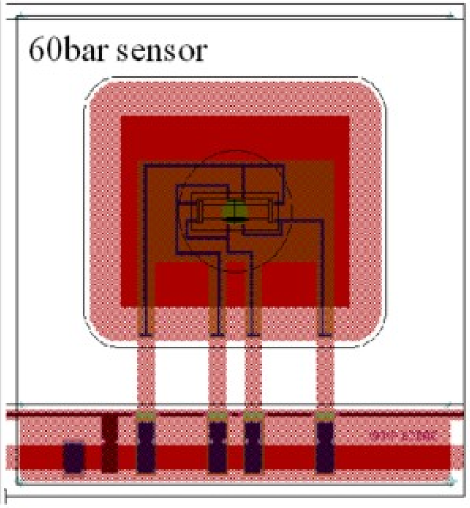
# Photo-lithograpy
# Transfer pattern from mask to film of photosensitive resist at silicon wafer surface



# Layout of lithographic masks

## L-Edit or Coventor Designer

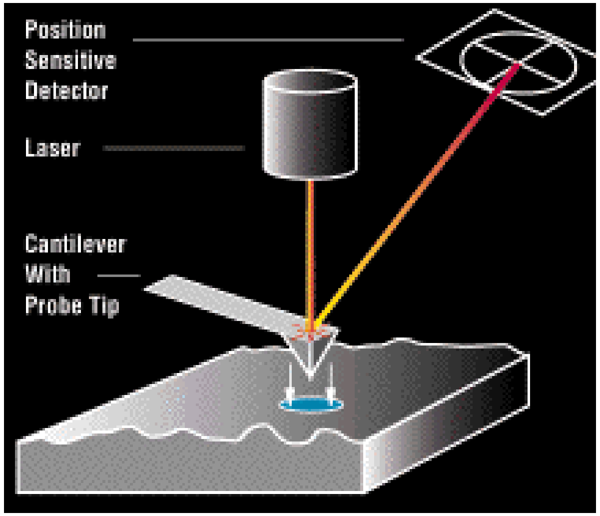


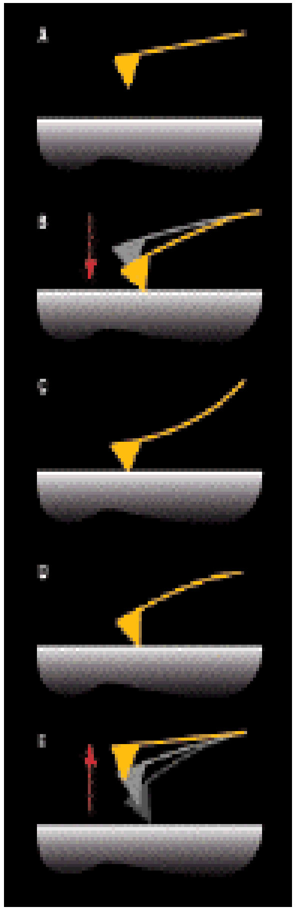


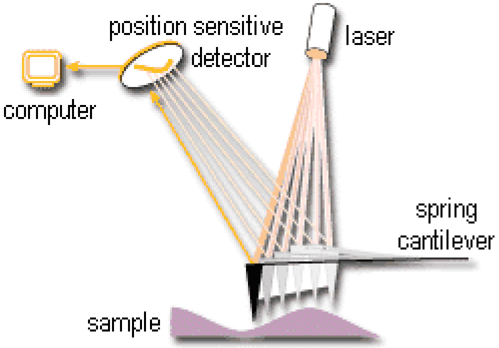
# Beam example: Atomic Force Microscope

- **Measures force between tip of cantilever and object**
- **E.g. forces from surface, weight of molecule**
- **Size of cantilever:**
  - **100-500 μm long**
  - **0.5-5 μm thick**

- **How to measure forces?**
  - **Deflection of beam due to force can be measured by reflection of light**
  - **Mechanical stress in beam is related to force and deflection and can be measured with piezoresistors**







# Beam example: Translating biomolecular recognition into nanomechanics
Science 288, 2000

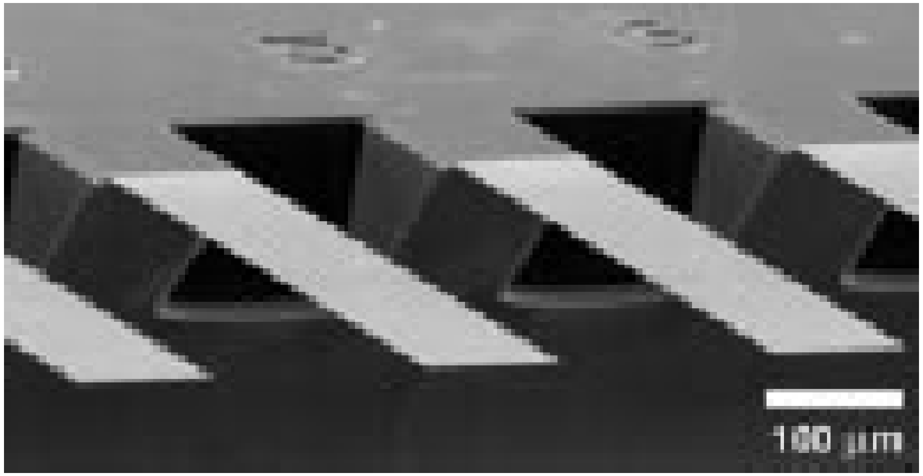


Fig. 1. Scanning electron micrograph of a section of a microfabricated silicon cantilever array (eight cantilevers, each 1 µm thick, 500 µm long, and 100 µm wide, with a pitch of 250 µm, spring constant 0.02 N m$^{-1}$; Micro- and Nanomechanics Group, IBM Zurich Research Laboratory, Switzerland).

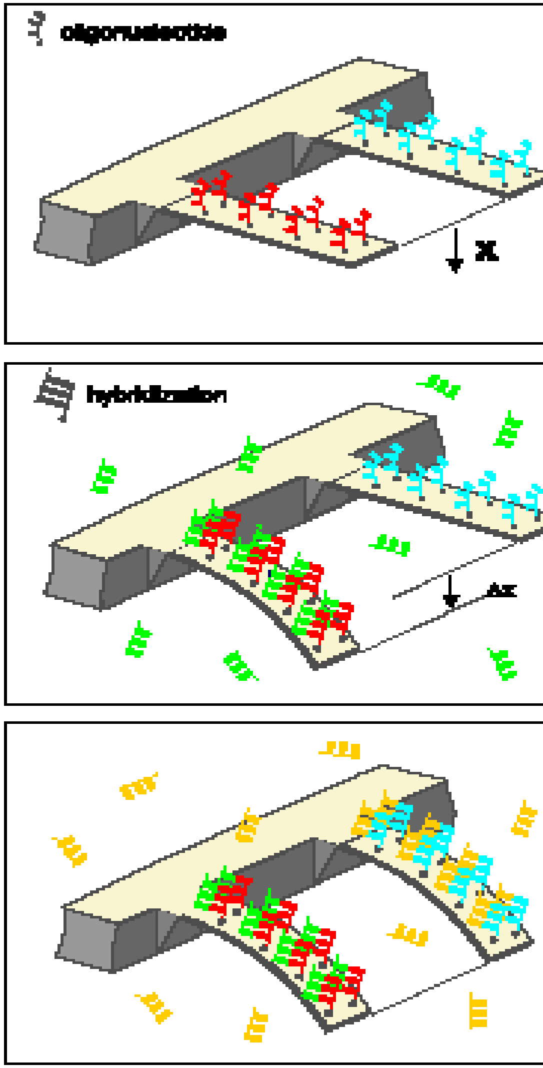


Fig. 2. Scheme illustrating the hybridiza
experiment. Each cantilever is functionalize
one side with a different oligonucleotide
sequence (red or blue). (A) The differe
signal is set to zero. (B) After injection of
first complementary oligonucleotide (gre
hybridization occurs on the cantilever that
vides the matching sequence (red), increa
the differential signal Δx. (C) Injection of
second complementary oligonucleotide (
low) causes the cantilever functionalized
the second oligonucleotide (blue) to bend.

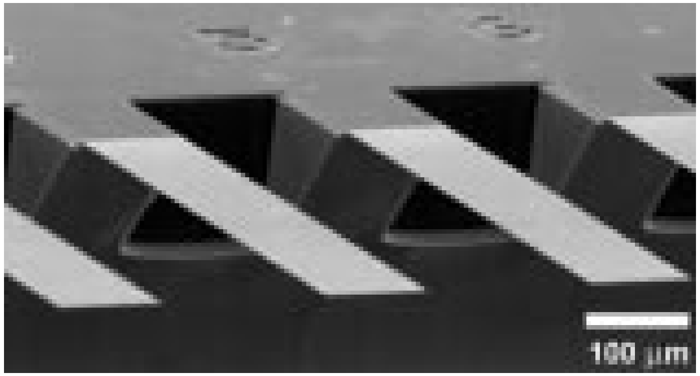
## Bulk silicon micromachining

# Funksjonaliserte overflater i biosensorer

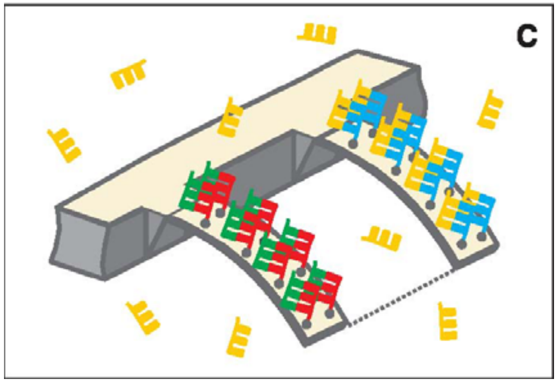
Eksempel på mekanisk sensor for bio-makromolekyler

Andre vanlige miniatyriserte biosensorer er basert på optiske- eller impedans målinger. Sensorene kan bli svært sensitive

Sensorens selektivitet er avhengig av bio-funksjonaliserte overflater



Silisiumbjelker med gull på oversiden, 1 µm tykke

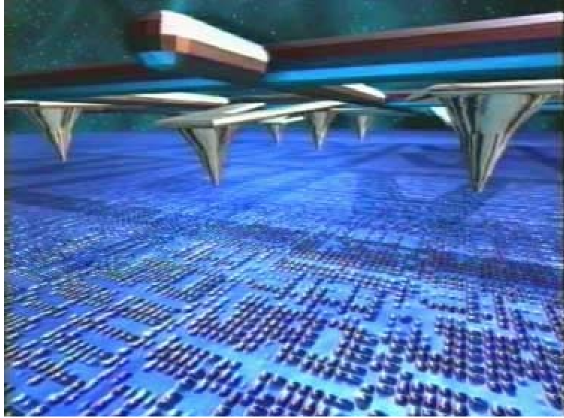


Silisiumbjelker med forskjellige immobiliserte monolag av thiol-modifiserte oligonukleotider på oversiden. Hybridisering til spesifikke oligonukleotider gir stress og utbøyning som kan måles

“Translating biomolecular recognition into nanomechanics”
Science 288, 2000, J. Fritz et al., IBM Research Zurich

# Beam example: Millipede, IBM Zurich

## Mechanical read / write memory



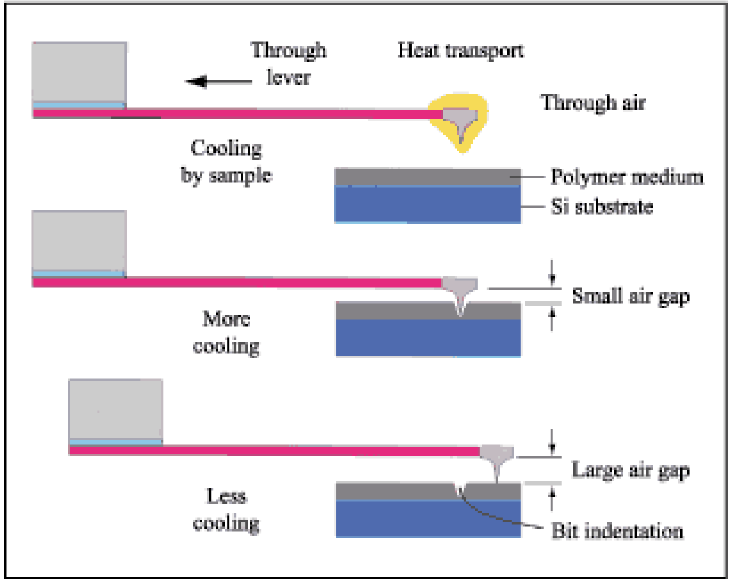


**Figure 4**

Principle of AFM thermal sensing. The heater cantilever is continuously heated by a dc power supply while it is being scanned and the heater resistivity measured. Adapted from [17(a)], with permission; © 1999 IEEE.

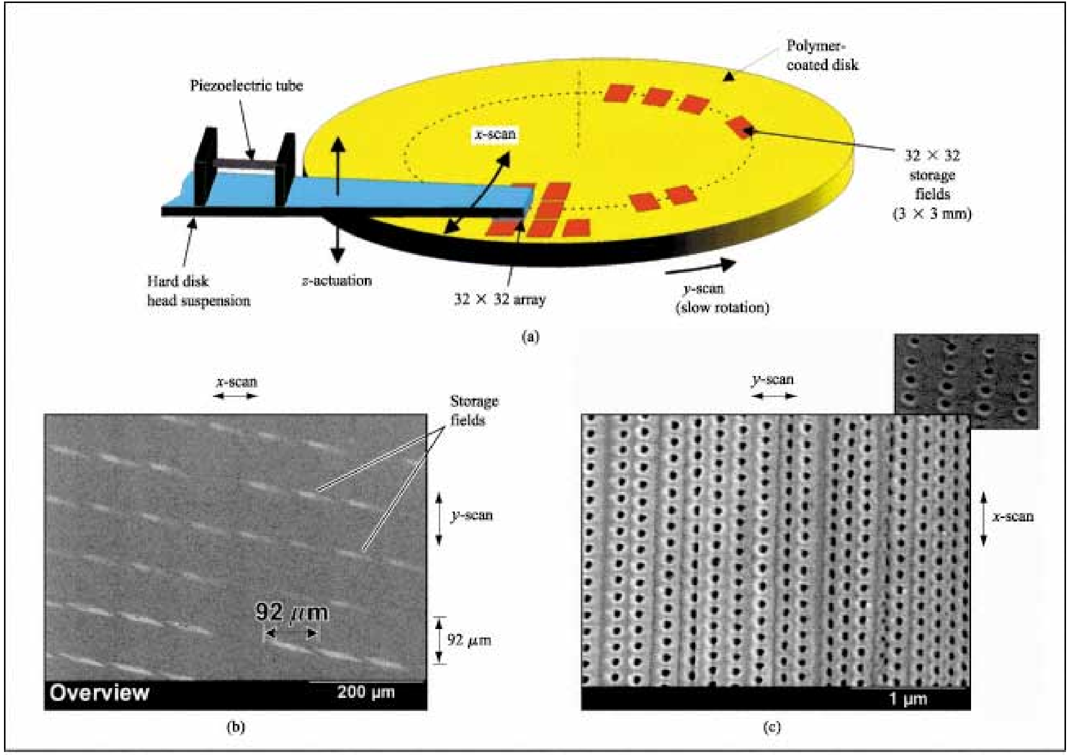


**Figure 14**

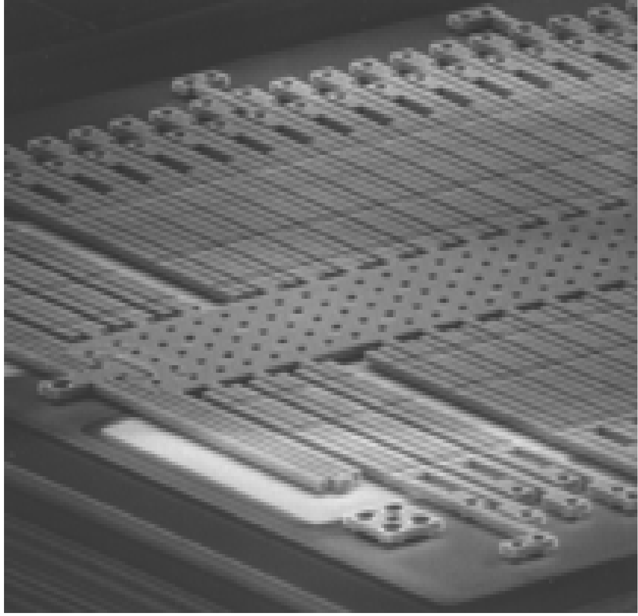
(a) Modified hard disk Millipede approach for array-chip scanning and displacement, and writing results: (b) SEM image of many storage fields; (c) magnified bit indentations in 100-nm-thick PMMA medium, equivalent to a storage density of 70–100 Gb/in.[2] Note that the $x/y$ scan directions are interchanged between (b) and (c).

# Capacitive surface comb-accelerometer

- Polysilicon

  Surface micromachining

Analog Devices

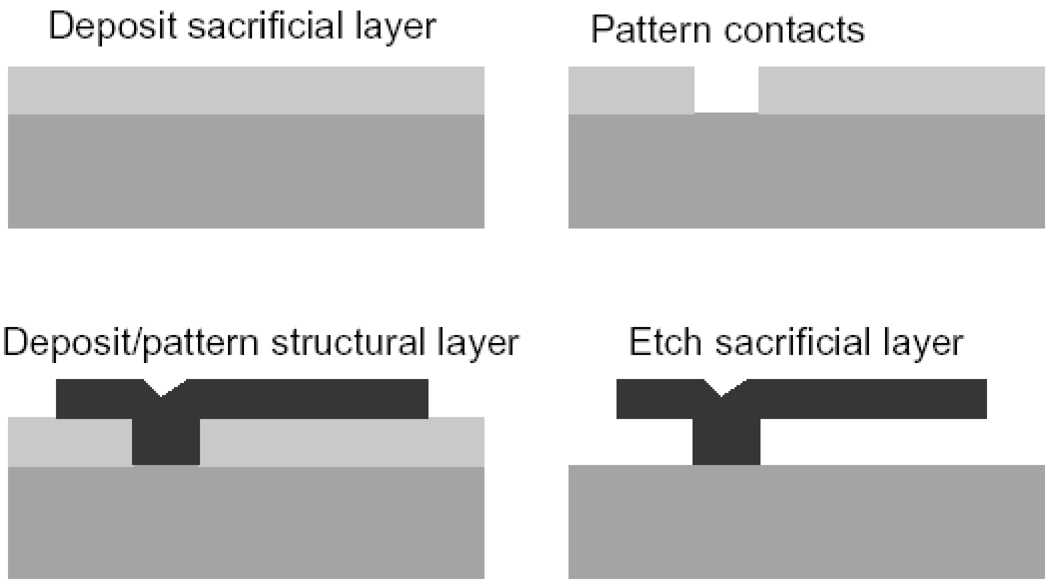


Design of:

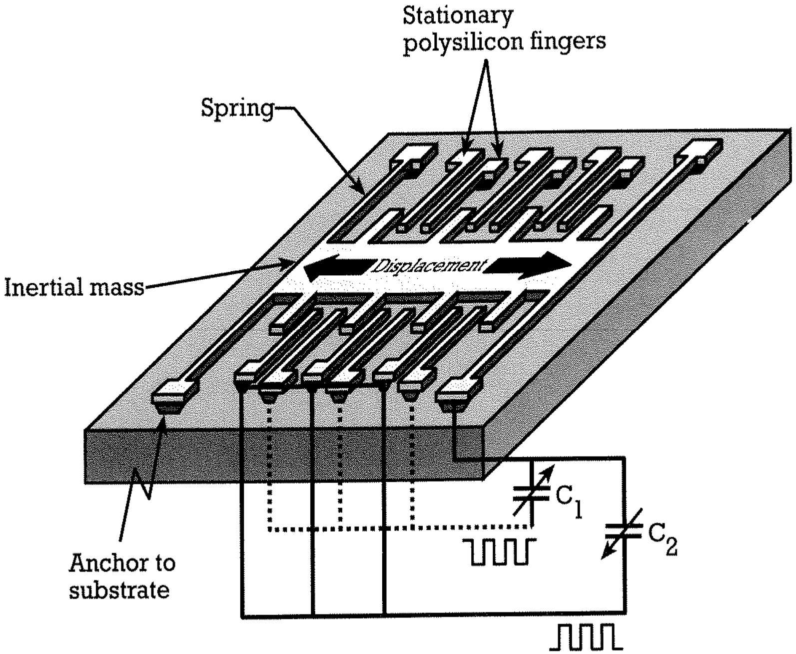
- Low-g accelerometer (5g)
- Capacitive read-out:

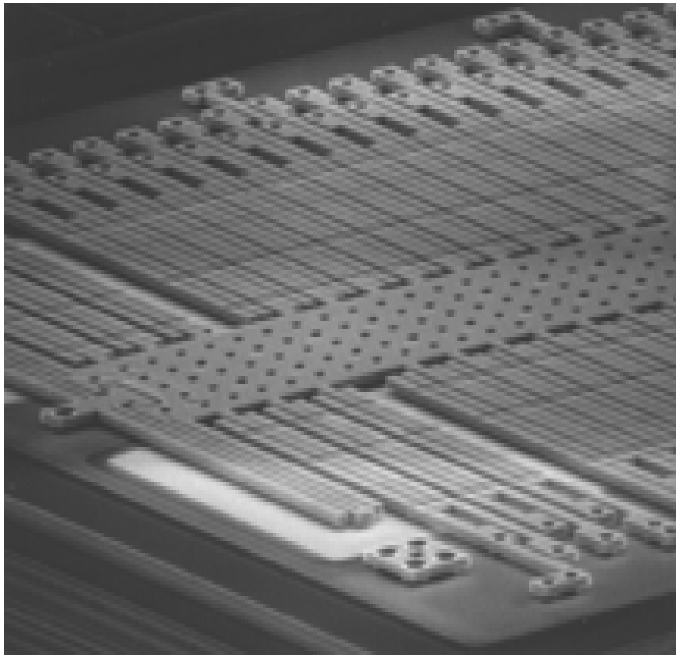
  collaboration with microelectronics

Self-test

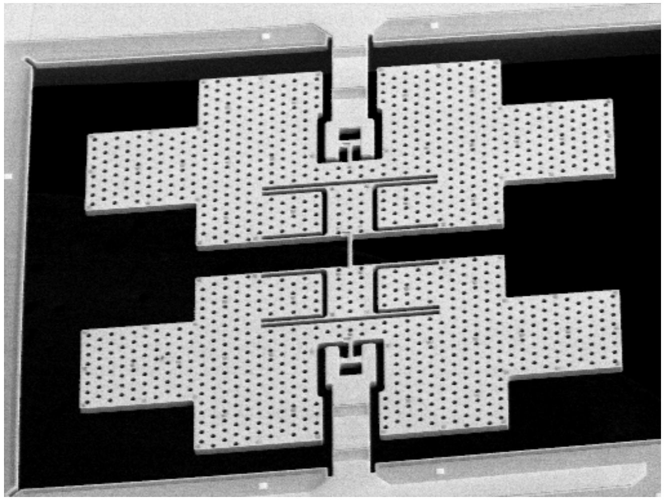


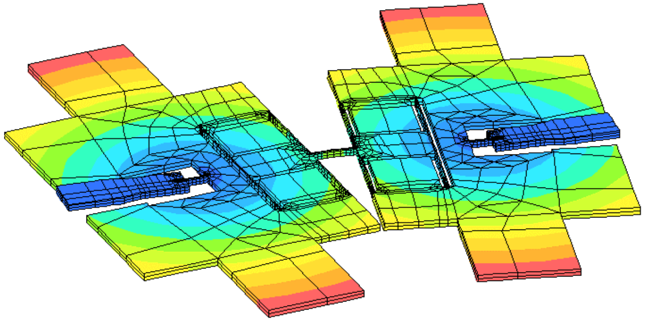
# A Capacitive Accelerometer

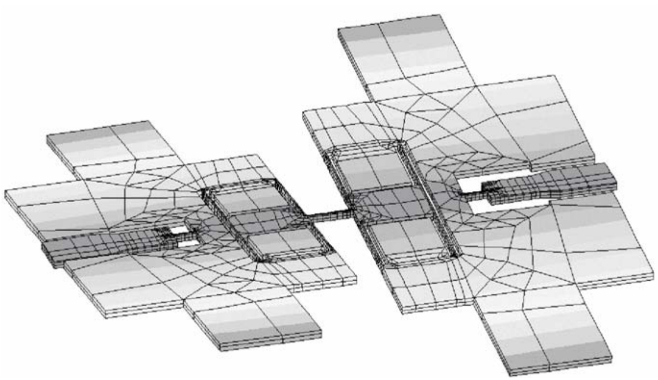


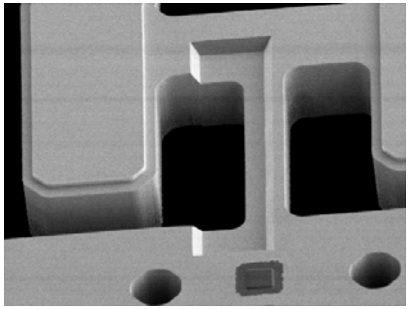


# Capacitive roll-over sensor: SensoNor's SAR100

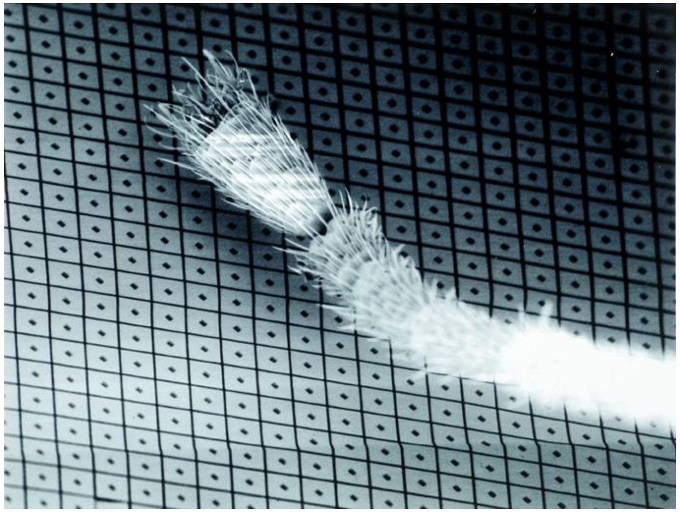




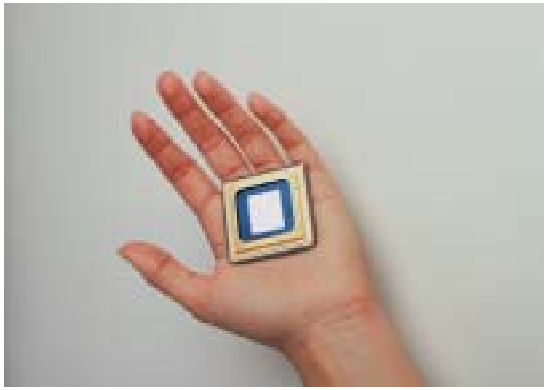




# Image projector
# with micromachined mirrors
# Digital Light Processing, Texas Instruments

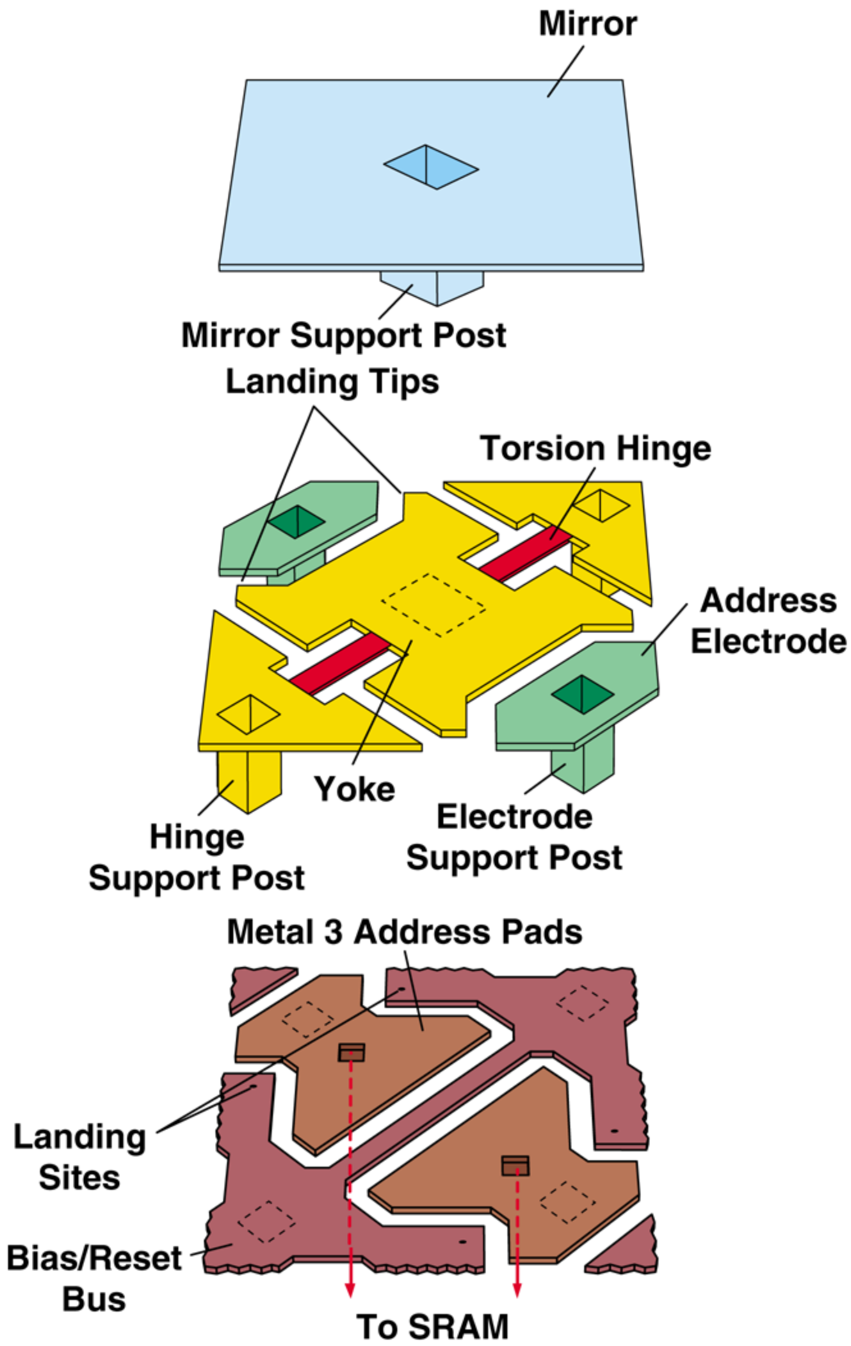


- Aluminium micromirrors fabricated on the surface of a silicon wafer with an integrated circuit
- Mirrors are individually controlled
- Size of mirror: 16$\mu$m x 16$\mu$m (?)
- Mirrors separated by 1$\mu$m
- One chip: 1920x1080 mirrors (2 073 600 mirrors)



# One micromirror

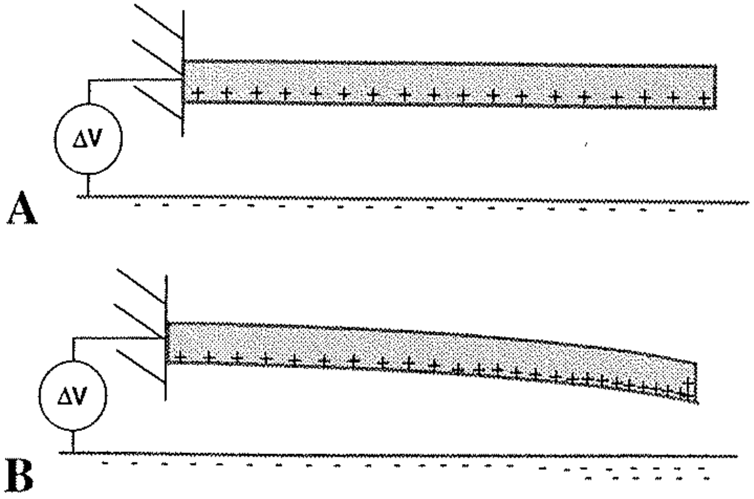
- Actuated by electrostatic forces: apply a potential difference between mirror and electrode
- Elastic torsion forces oppose the tilt



# DLP pico projector

# Electro-Mechanical behaviour

- Coupled electro-mechanical problem



Governing equations

- Electrostatic potential between electrodes solving the Laplace equation
- Elasticity equation solved inside the beam

Solve

- Solve fully coupled systems of partial differential equations
- Alternately solve equations until equilibrium is reached

Surrounding fluid/gas

- Reynolds equation solved separately
- Viscous damping, film spring effect

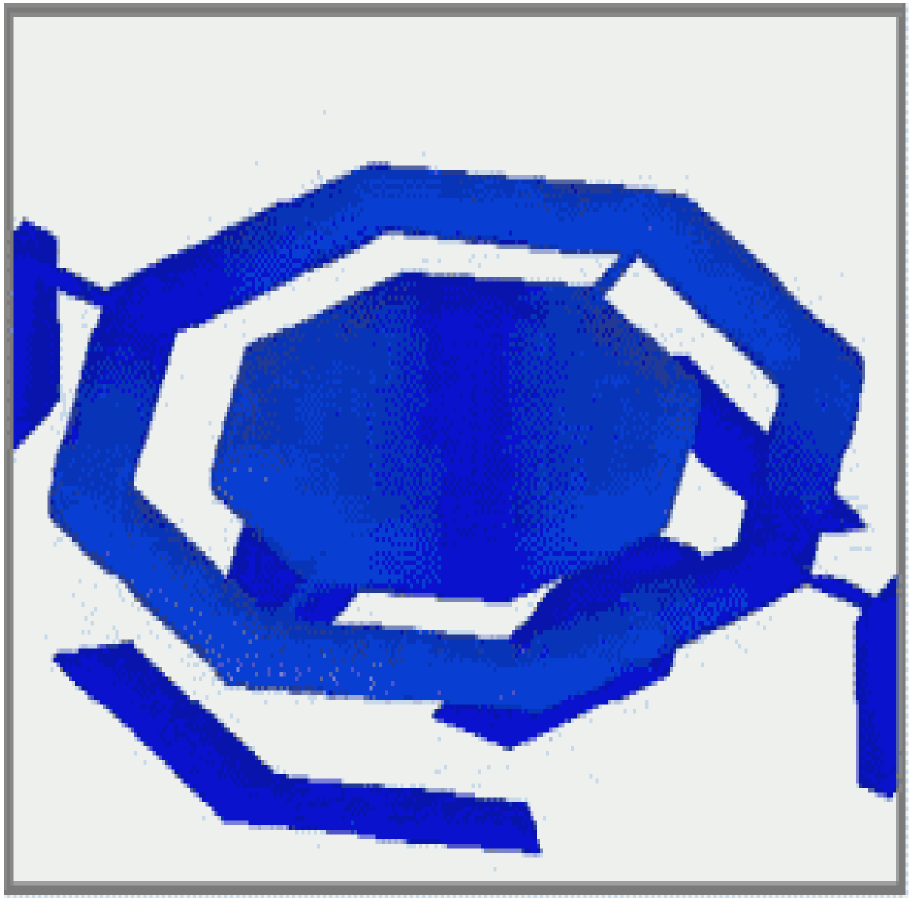
# Mechanical and electrostatic equations

- Naviers equation for elastic forces: (isotropic version)

$$(\lambda+\mu)\nabla\nabla\cdot u+\mu\nabla^2 u=0$$

- Poisson equation for electrostatic field:

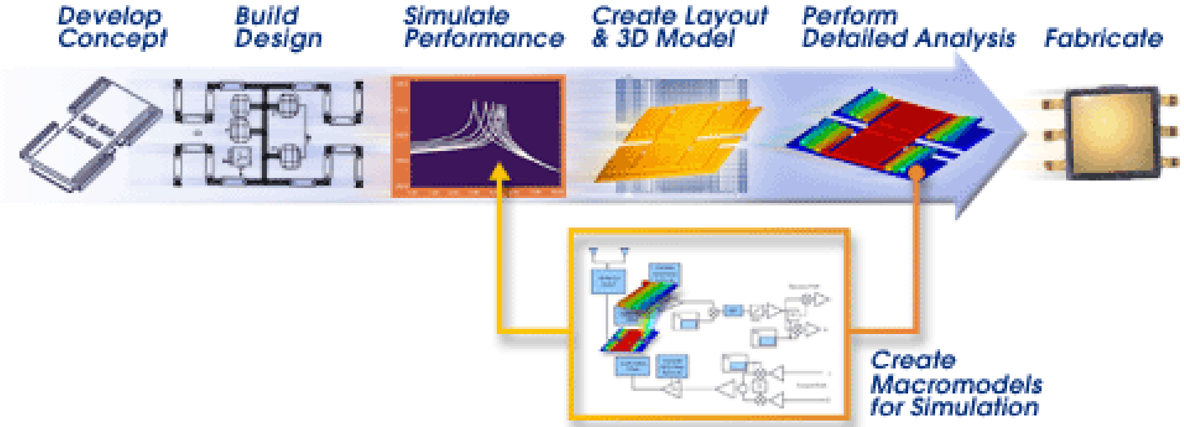
$$\nabla^2\Phi=-\frac{\rho}{\varepsilon}$$

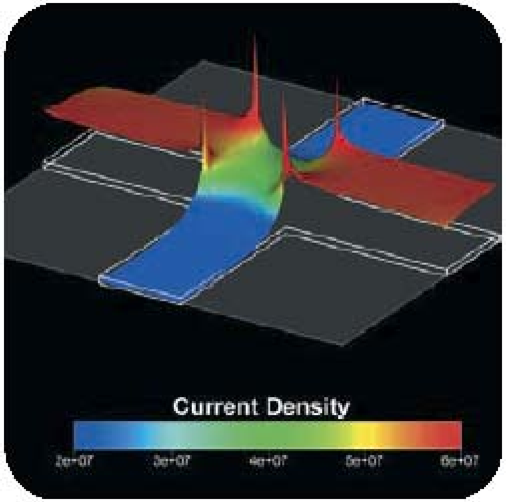


# Coventorware  Designer / ANALYZER

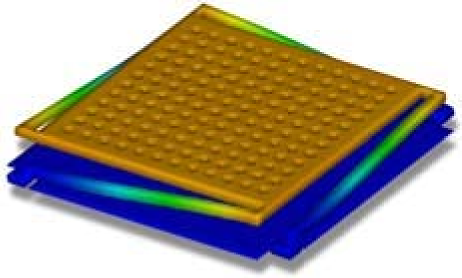
- Device modelling
- Continuum mechanics
- Electromagnetism
- Piezoresistivity

- Optics
- Piezoelectricity
- Fluidics



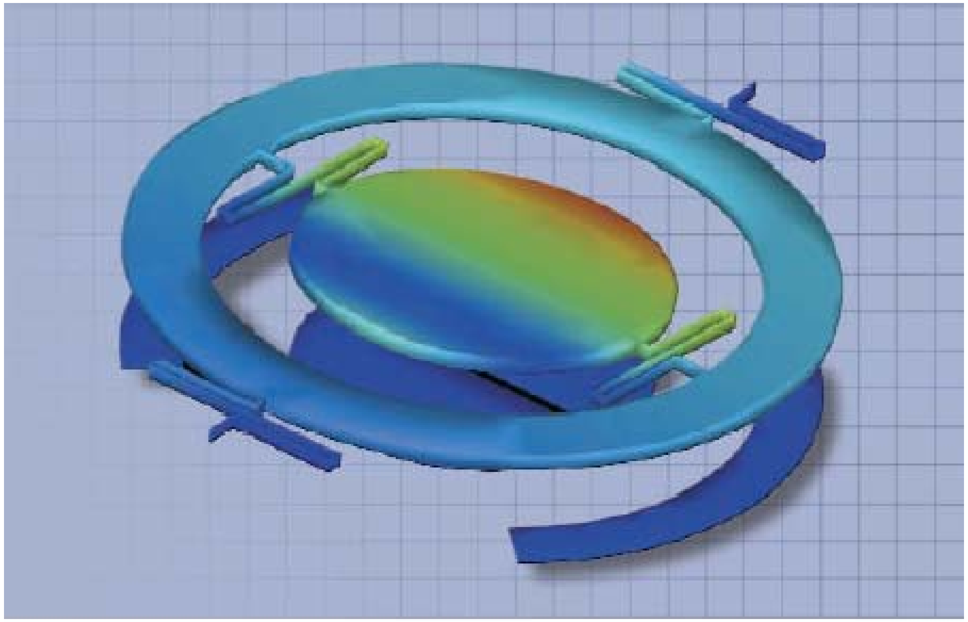


*MemPZR analysis of a piezo-resistor cross*

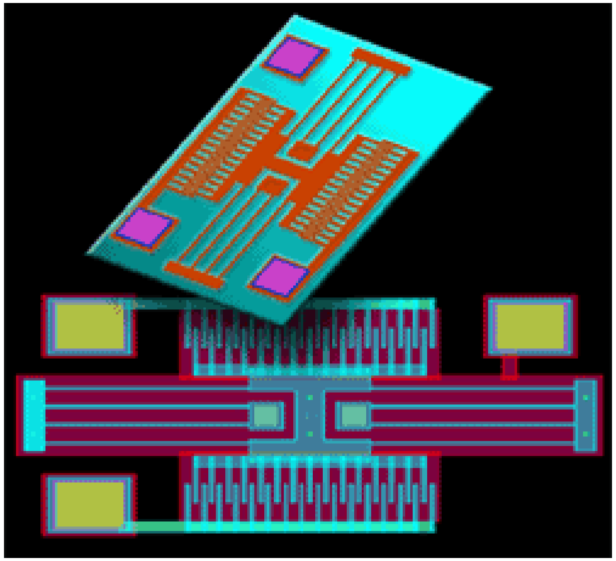


# Coventorware Microsystem modelling and layout

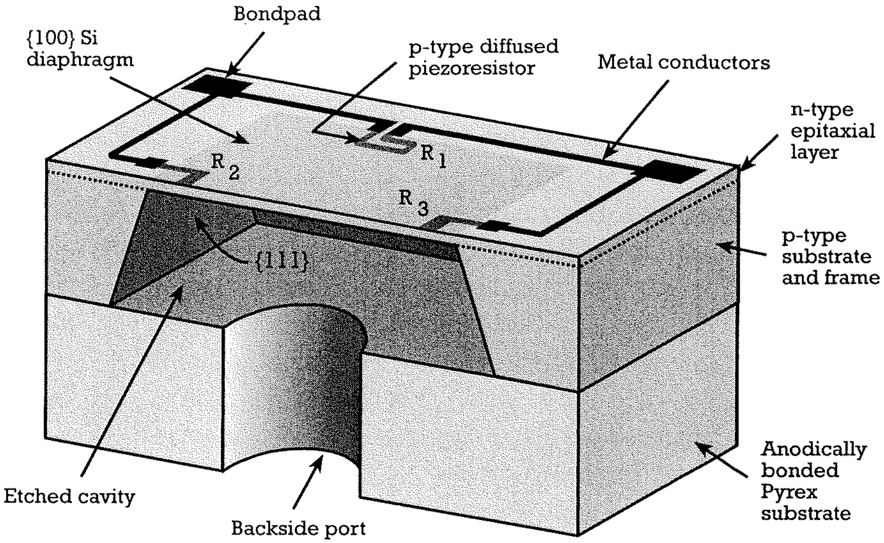
- Process generation
- **Mask layout**
- **Device modelling**

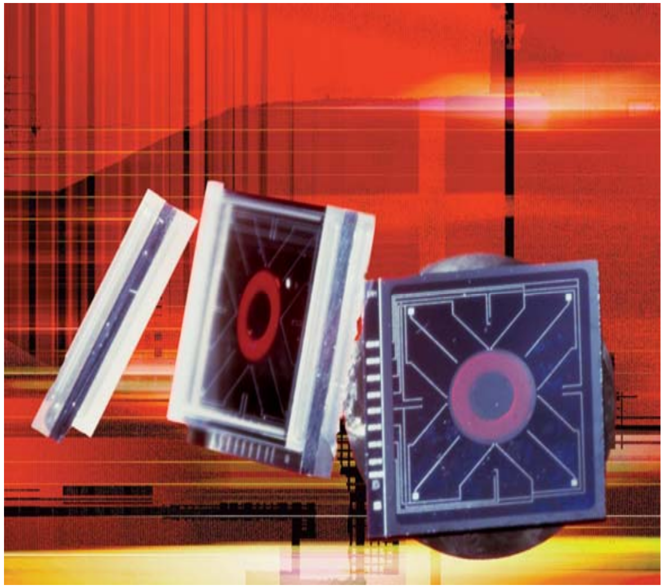


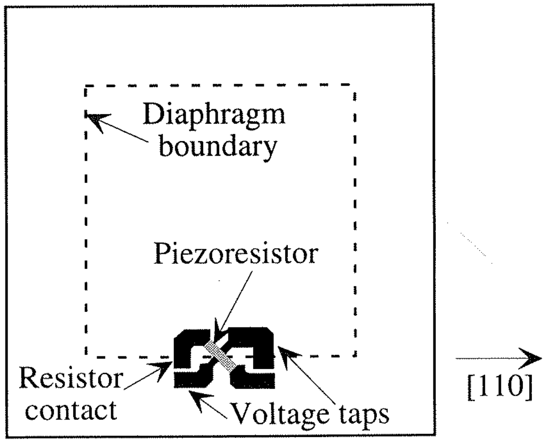
Analysis of a MEMS mirror illustrates the relative displacement of its components. You can also analyze modal frequency, residual stress, maximum stress, electrostatic force of electrodes, beam diffraction, and crosstalk between multiple mirrors in an array.



# Piezoresistive pressure sensors







# Mechanical modelling

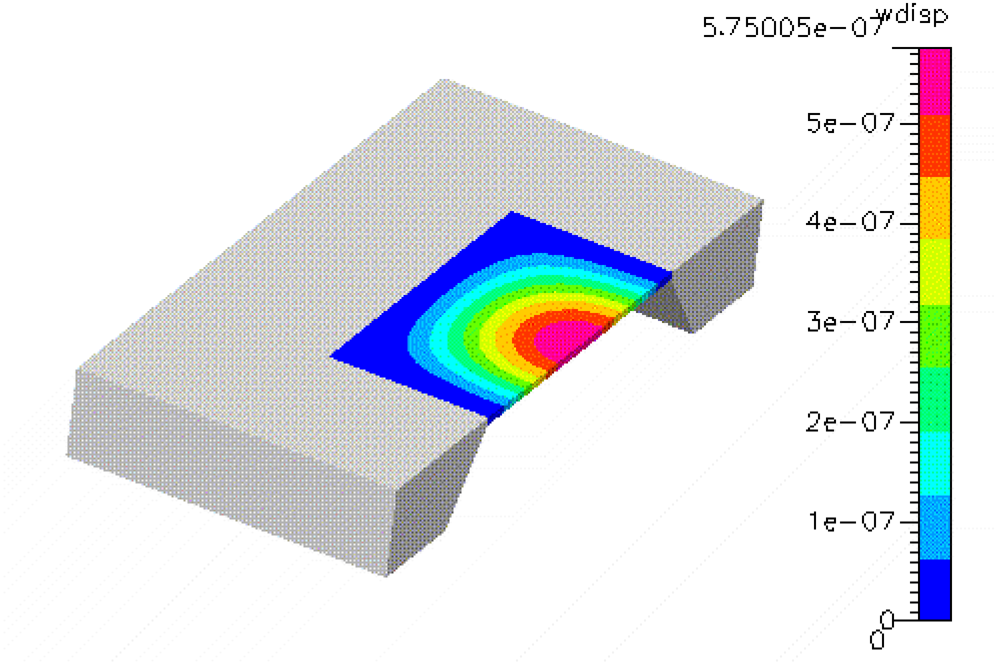
- Deflection of mechanical elements due to forces
- Stress in mechanical elements
- 3D elasticity equation, plate or beam equations
- Crystal silicon

Membrane etched in single crystal silicon:

- Material parameters:

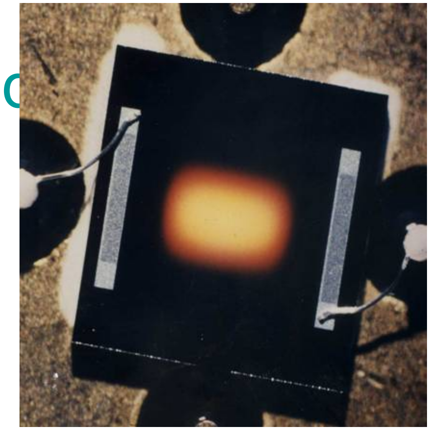
E=1.698x10$^{11}$ N/m$^{2}$,
v=0.066

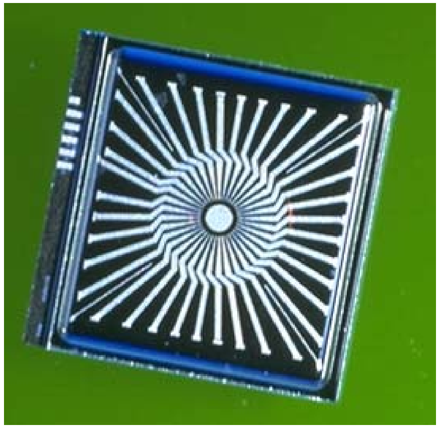
- Analytical solution
Wmax=5.732 x 10$^{-7}$m

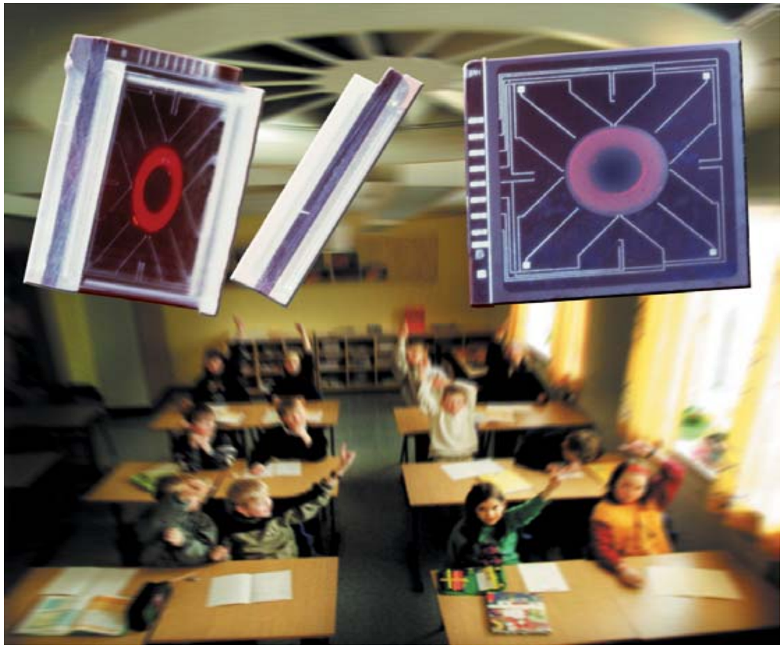


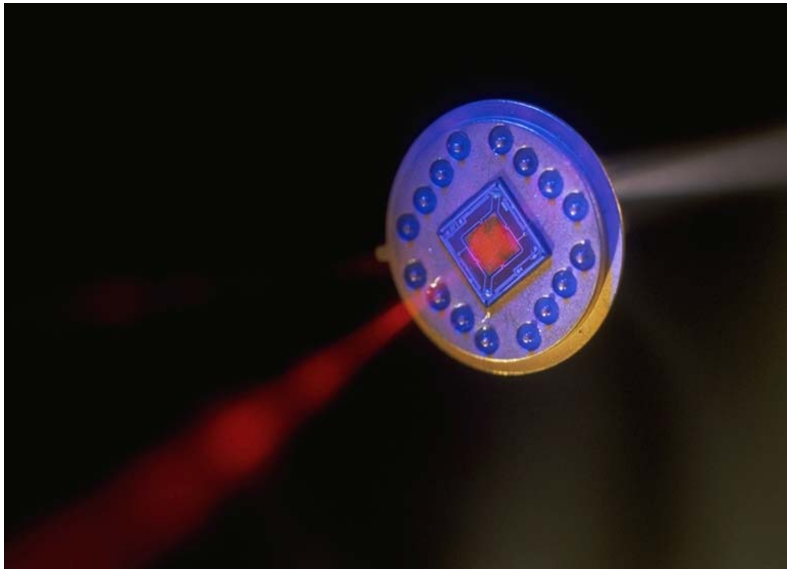
# Photoacoustic gas sensor

- Combination of 3 micromachined elements, SINTEF patents
- SensoNor Microsystems Products



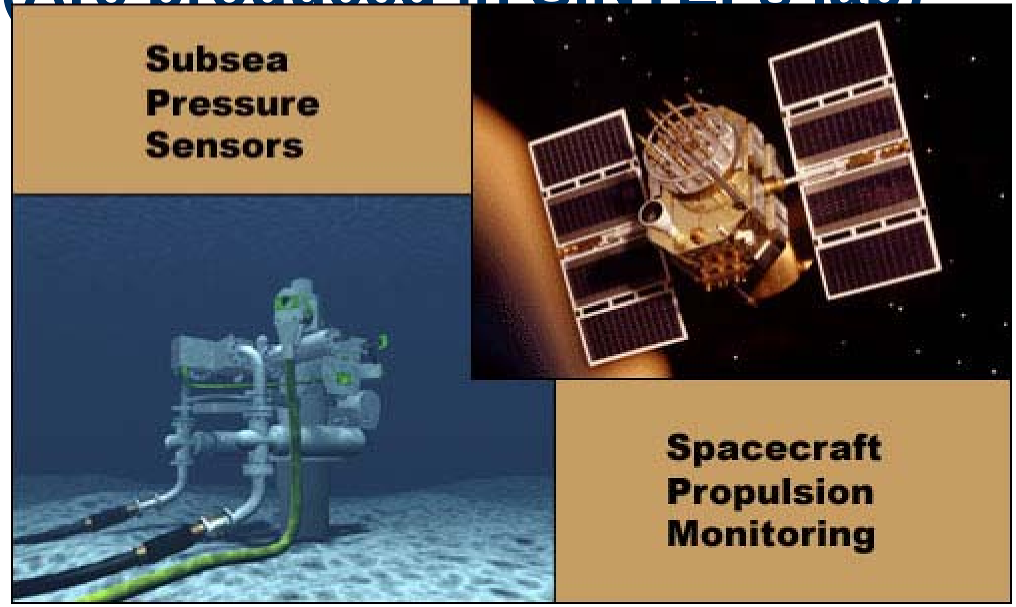


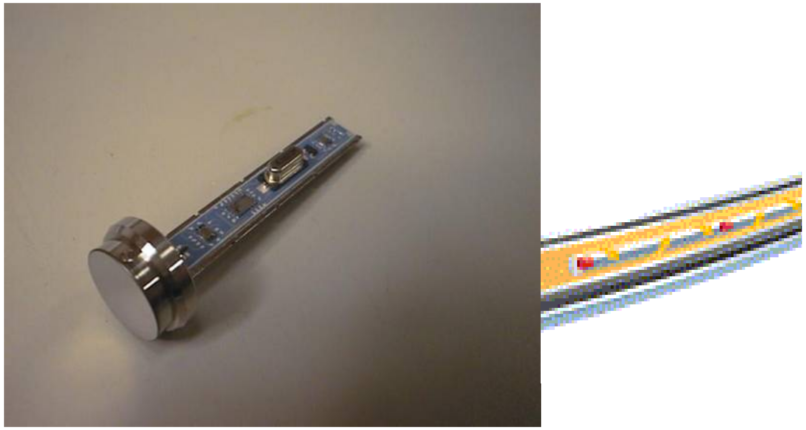




# Pressure sensor for high pressures (2000 bar)

## (Are produced in SINTEFs lab)

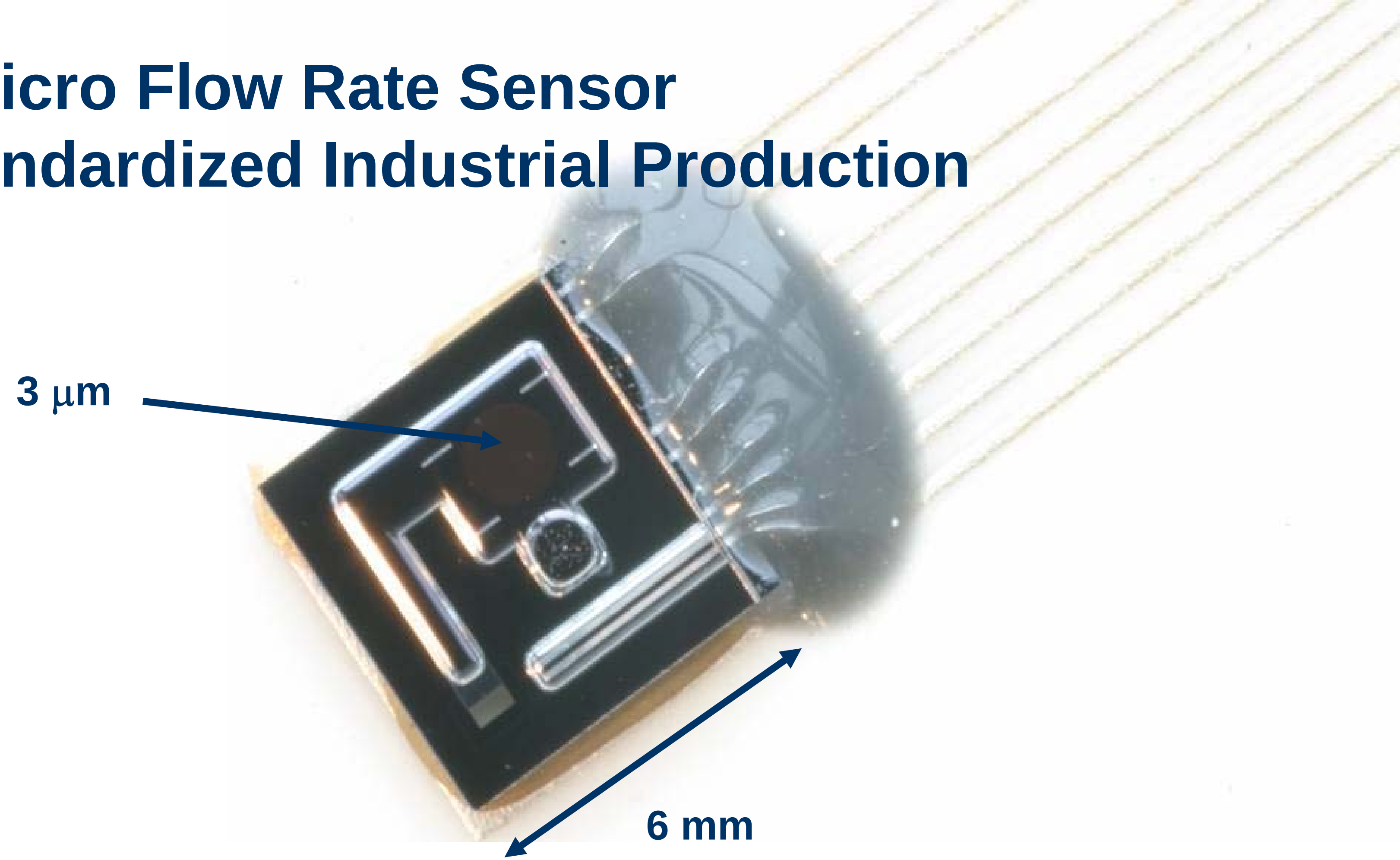




PRESENS

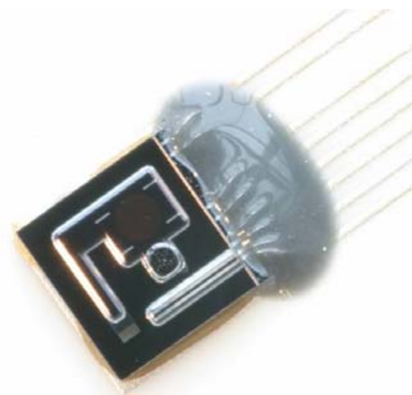
STATE OF THE ART SENSOR SOLUTIONS

# New Micro Flow Rate Sensor for Standardized Industrial Production



**Microsystems and Nanotechnology**
**SINTEF Information and Communication Technology**

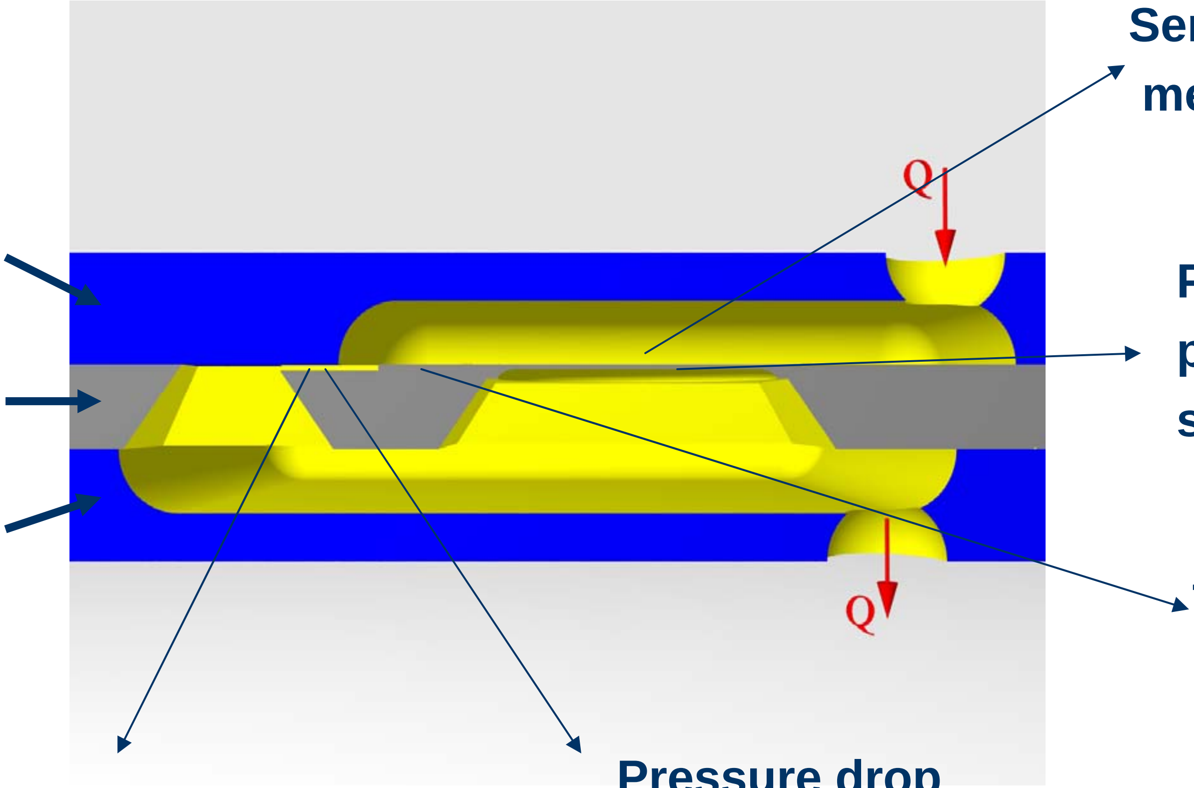
# The world’s leading manufacturing line for tire sensors is used for production of the flow sensor



The SensoNor foundry produces a micro-fluidic element for the first time

An Infineon Technologies Company

# The new design suggests a low-noise, mechanically robust flow sensor



Sensitive and strong membrane

Pyrex

Silicon

Pyrex

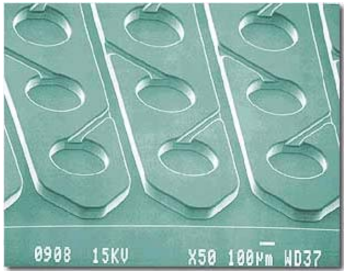
Protected piezoresistors for stress measurements

Temperature sensing diode

Channel depth 11 µm

Pressure drop proportional to the flow rate

# Micro-channels

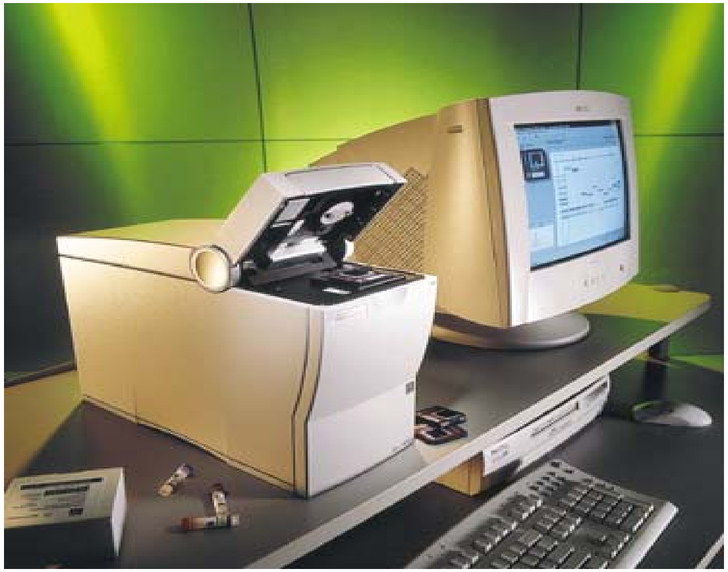


- Kanaler med vertikale vegger i silisium

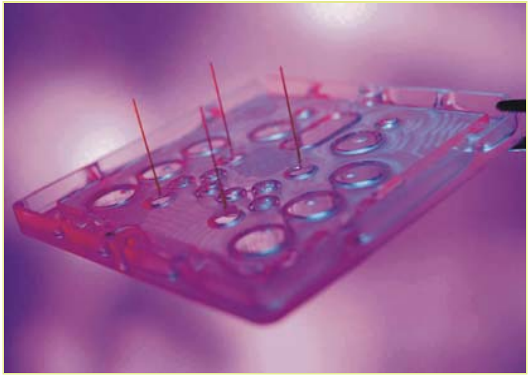
- Sprøytestøping av plast

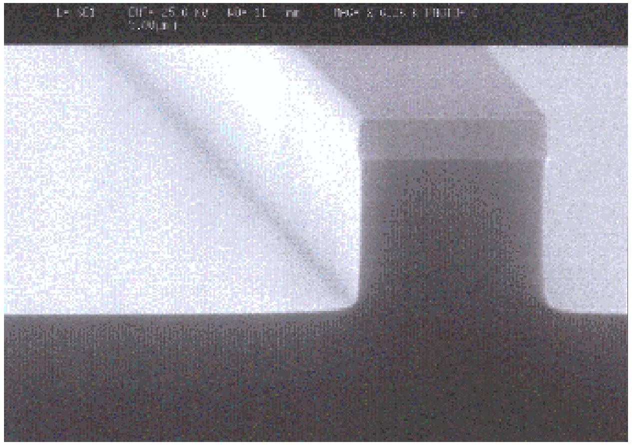
  Støpeformene generert f.eks. via silisium + elektropletering

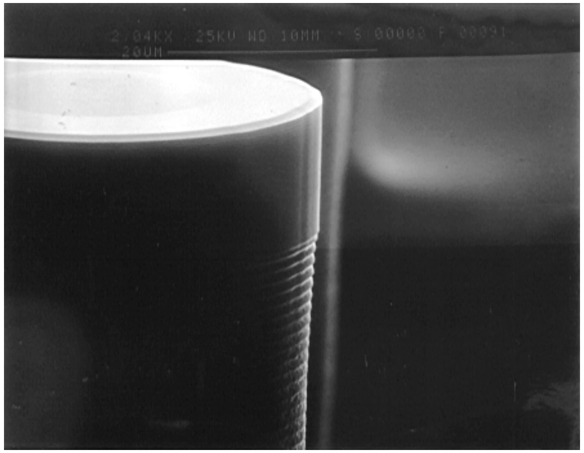
  - eller frest i messing



Caliper





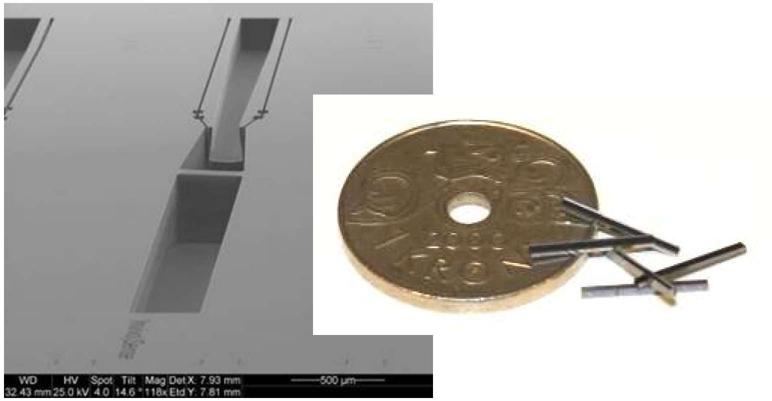


New:
Deep reactive ion etch DRIE, BOSCH process

# Microfluidics

- Lab-on-a-chip for diagnosis
- Microfluidic handling
- Real-time RNA amplification
- Fluorescent read-out

Lab-on-a-chip

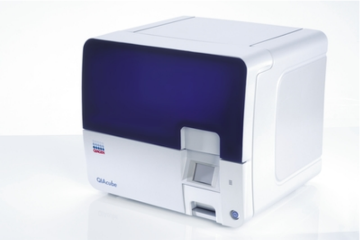


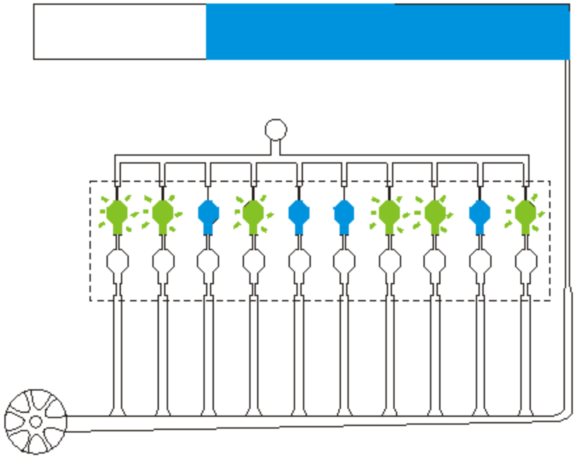
Invivo biosensor

Microfluidics lab

# MicroActive

- An instrument for molecular diagnostics intended for use in the doctor’s office
- Two lab-on-a-chip systems and two analytical instruments (designed to be put together)
- The two microfluidic chips where for
  - purification of nucleic acids (IMM, Germany)
  - detection of virus based on mRNA (SINTEF)






SINTEF injection molded chip

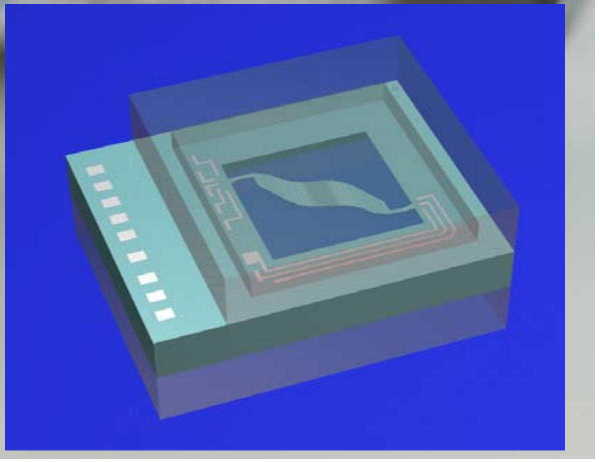
In cooperation with NORCHIP

# Surface modification

- Hydrophilic / hydrophobic surfaces
- Lithographic patterning
- E.g. deposition of self-assembled -monolayers

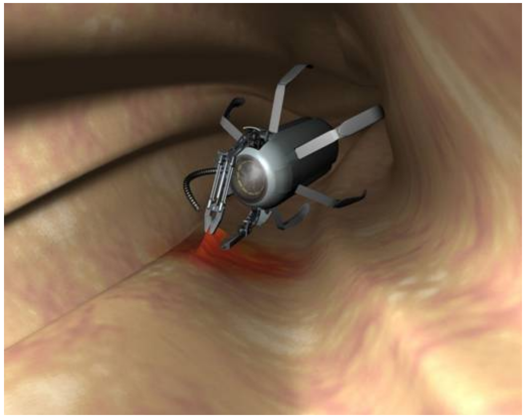
- Chemically active surfaces
- Biotechnologically active surfaces

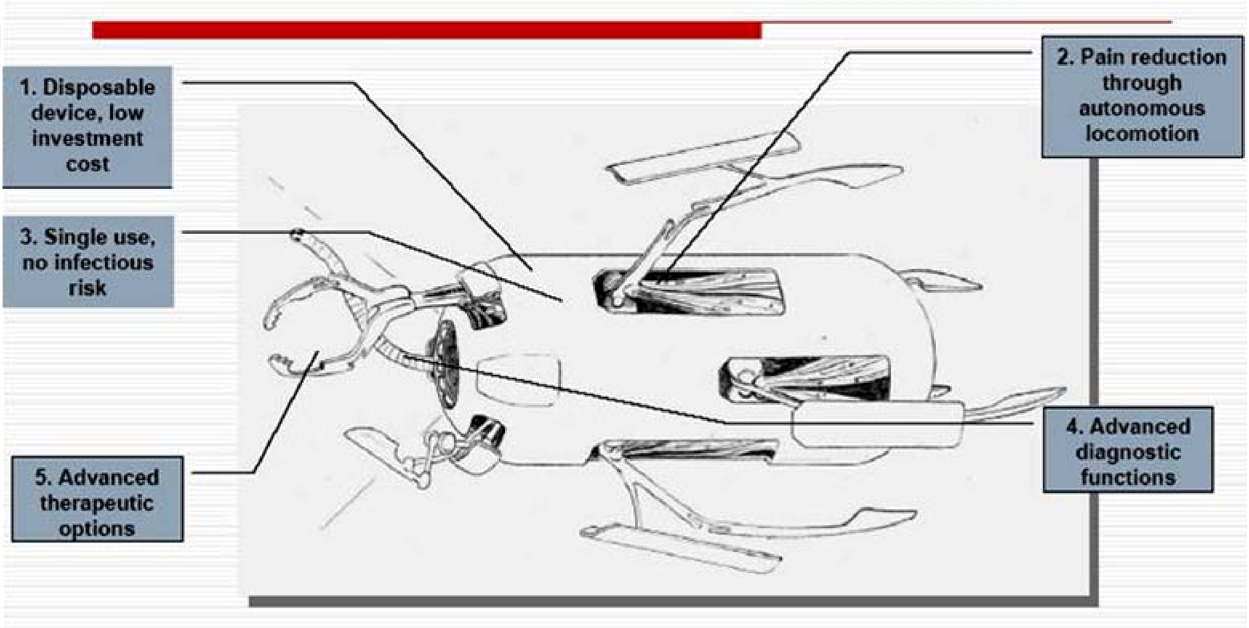
- Resonance shift due to attached molecules
- E.g. thermal actuation of resonance vibrations



# VECTOR

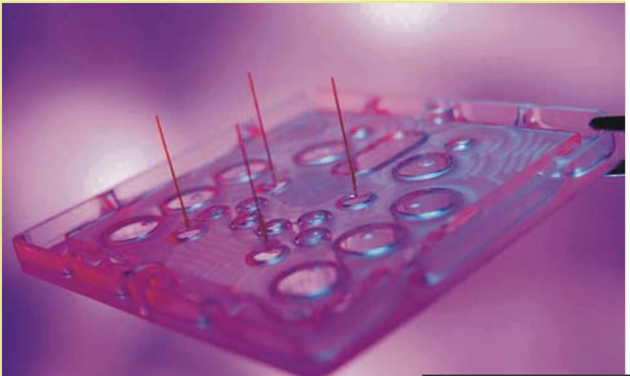
- Versatile Endoscopic Capsule for gastrointestinal TumOr Recognition and therapy
- Realizing smart pill technologies and applications for gastrointestin and therapy



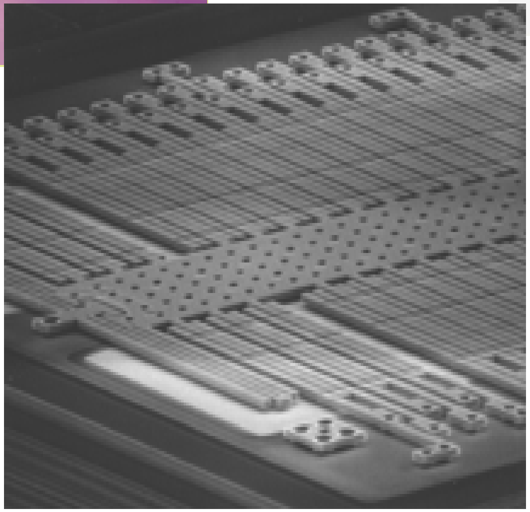


# Course contents, 4 main “cases”:

1) Micro fabrication and materials
2) Design of lithographic masks
3) Physics governing behaviour of  microsystems
4) Modelling of microsystems behaviour

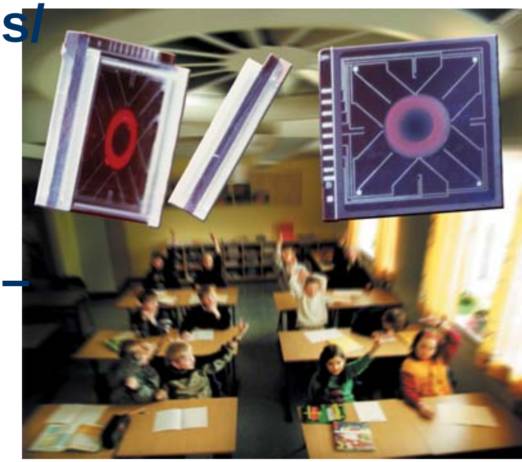


PCR analysis – microfluidics



Accelerometer – Inertial forces

Projector – optics/mechanics/ electrostatic



Pressure sensor– elasticity/ electronics