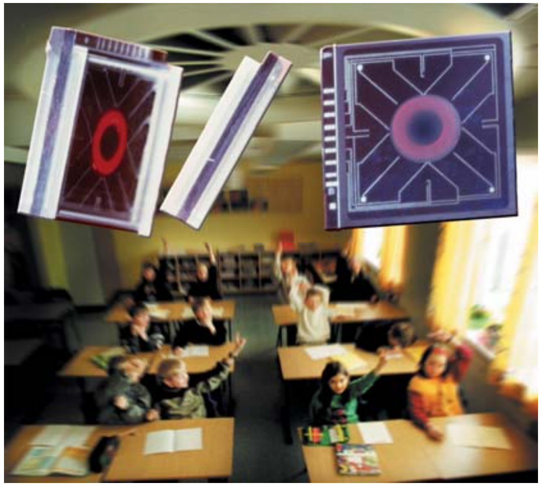
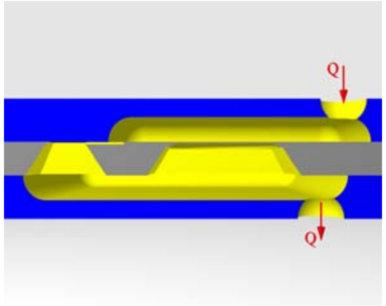
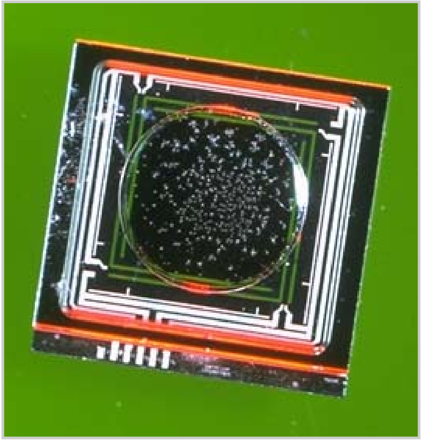
Fys4230
Mikro- og nanosystem modellering og design

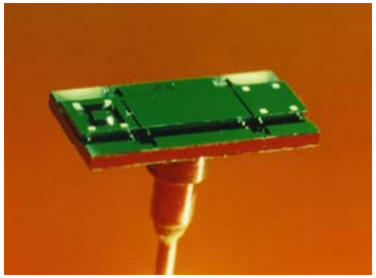
10 studiepoeng høsten 2008

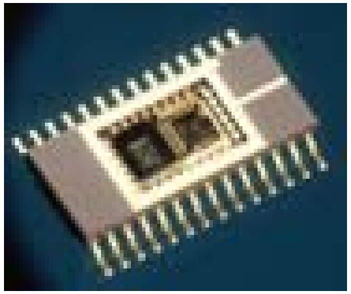


Ansvarlig: Liv Furuberg
SINTEF Informasjon og kommunikasjonsteknologi









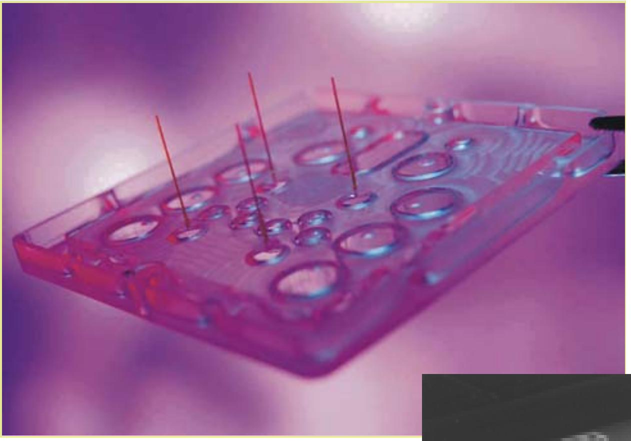
web page with all course information

- http://www.uio.no/studier/emner/matnat/fys/FYS4230/h08/

- Messages, keep yourself updated!
- Powerpoint presentations from lectures
- Exercises
- 2 compulsory exercises, deadlines

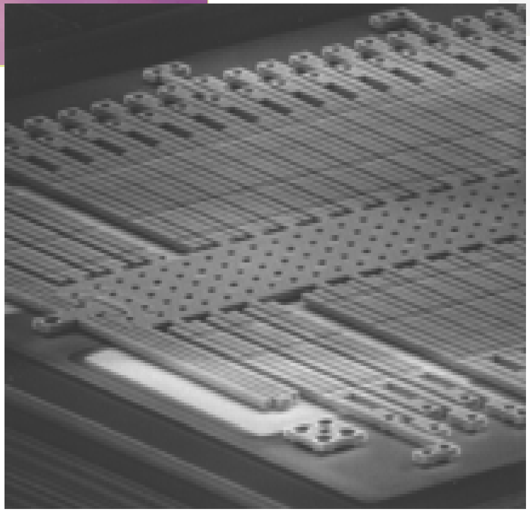
Course contents, 4 main “cases”:

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

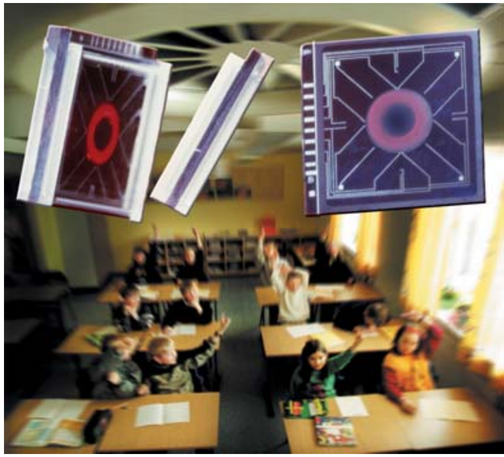


Lab-on-a-chip

Projector

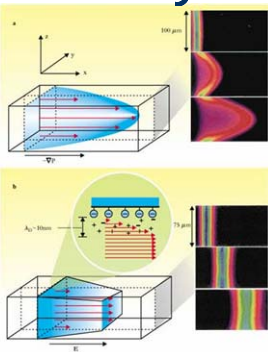


Accelerometer

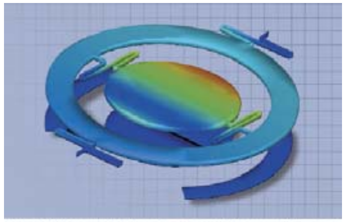


Pressure sensor

Fluid dynamics

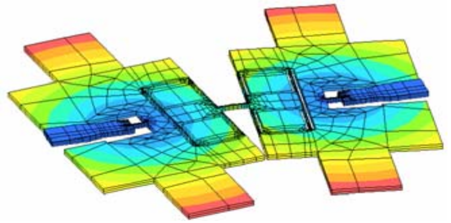


Multiphysics



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

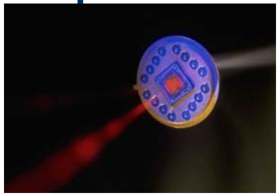
Electromagnetism

Chemistry

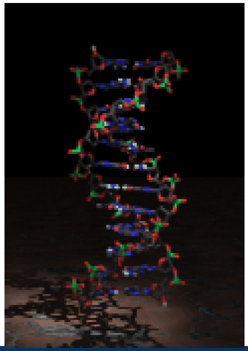
Challenge:

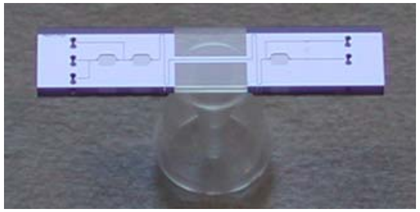
Design functional elements that can be manufactured by microtechnology

Optics



Biotechnology



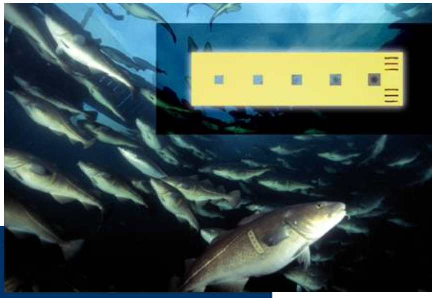


Capillary flow

Surface physics

Functional thin films

Material science



MiNaLab i Oslo

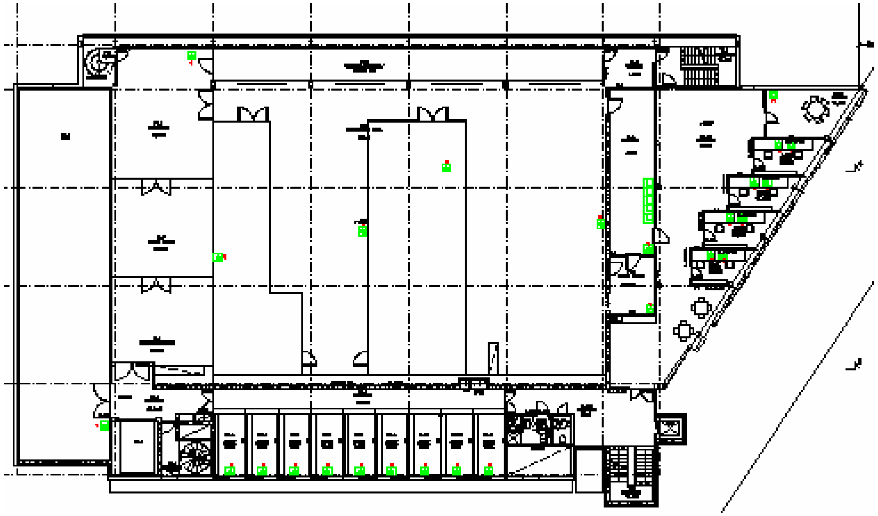
- Mikro- og Nanoteknologilaboratoriet I Gaustadbekkdalen
- MiNaLab

- Mikrosystemer =
  TVERRFAGLIGHET!

MiNaLab

SINTEF:

- Renromsareal: 800 m^2
- Microenvironments med klasse 10
- Ballroom: klasse 1000
- Produksjonslinje med årlig kapasitet opp til 8000 silisiumskiver

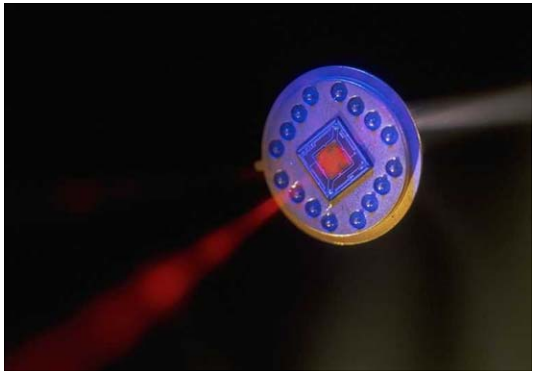


Universitetet i Oslo:

- Renromsareal 400 m^2

- Utstyr: NFR
- Bygget: SINTEF + NFR

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



•Sensors and actuators

•The functional element is of micrometer scale

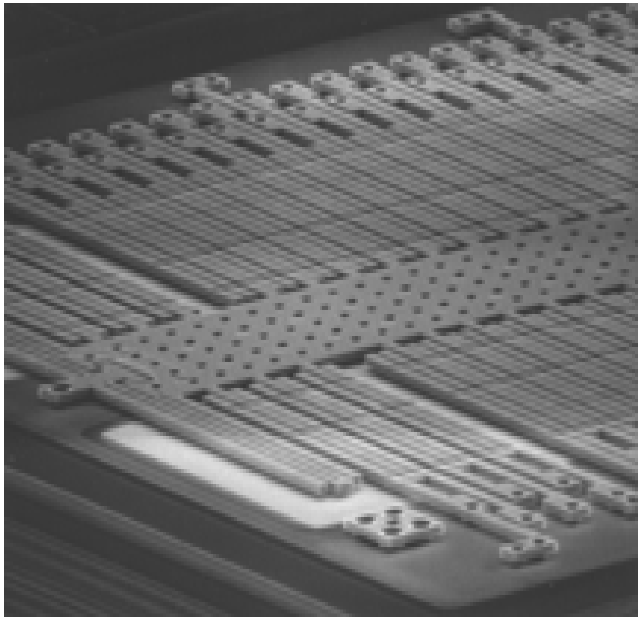
•Made from silicon, quartz or polymer

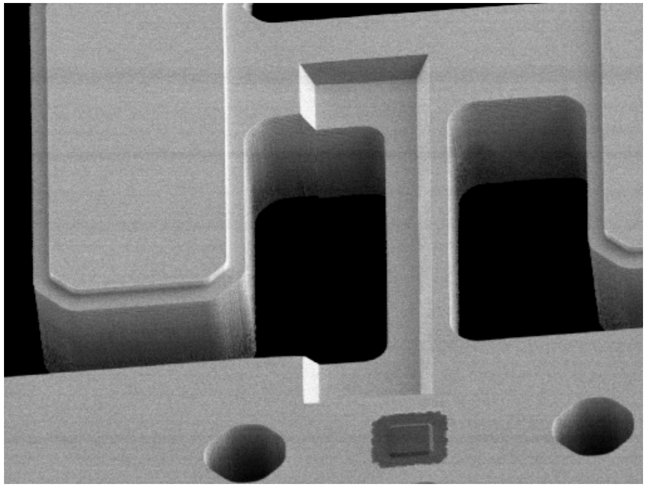
•Integrated with electronic circuits

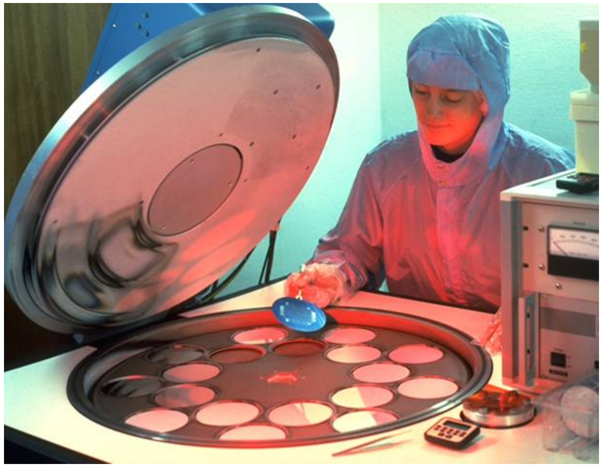
•Produced using integrated circuit fabrication technologies

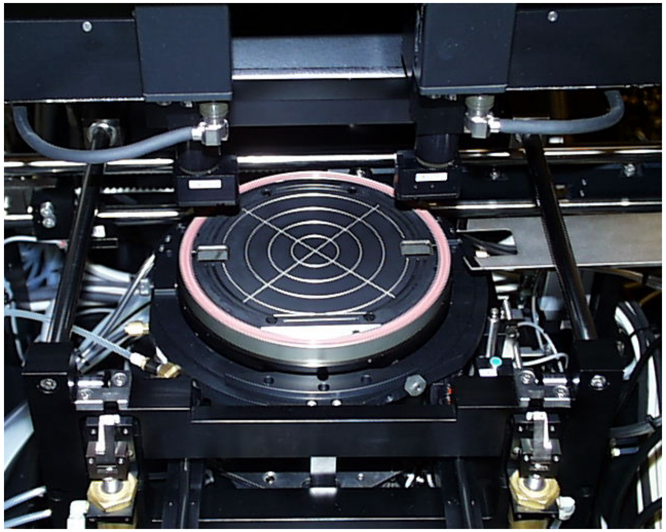
Micromachining

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





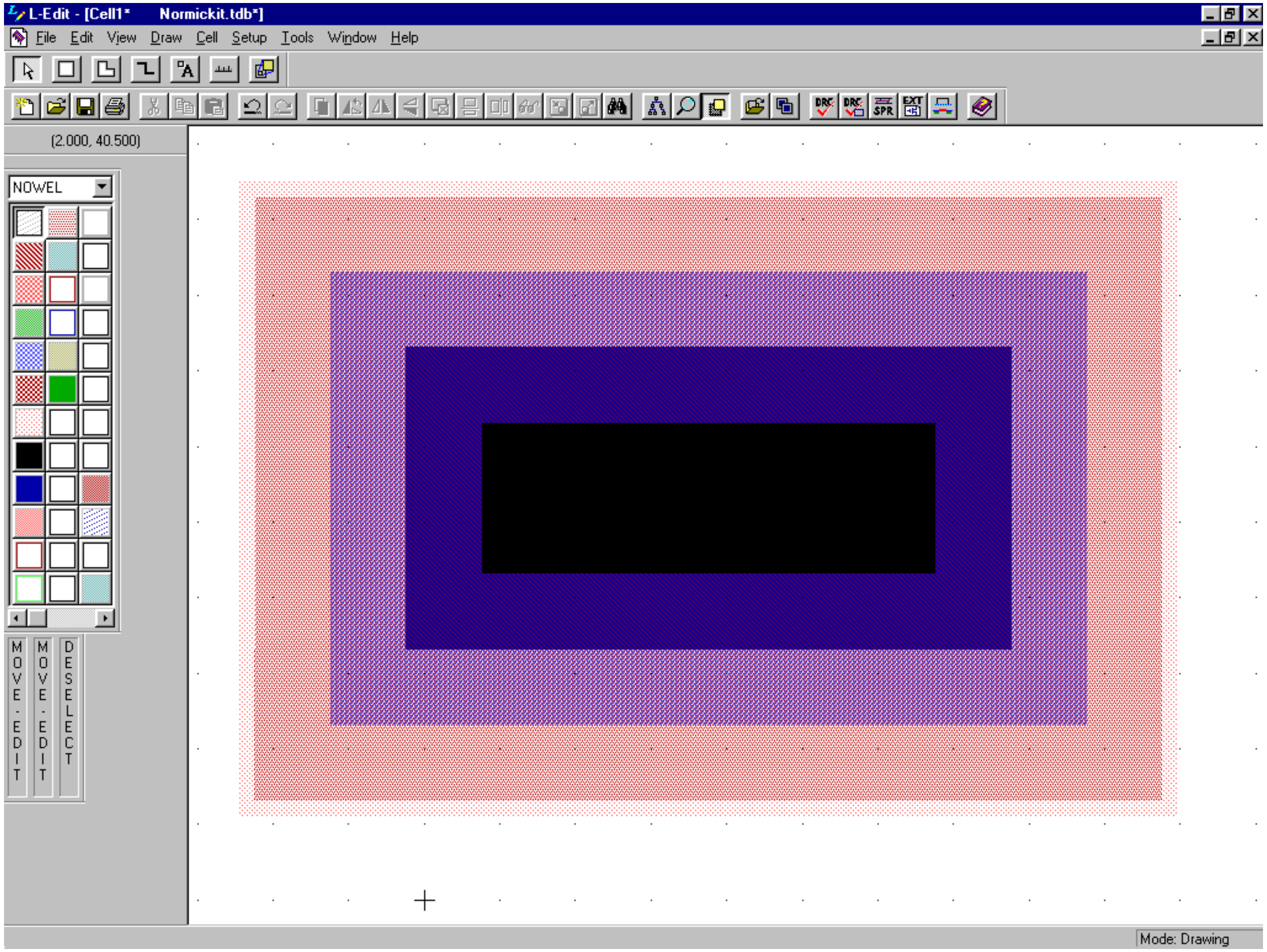


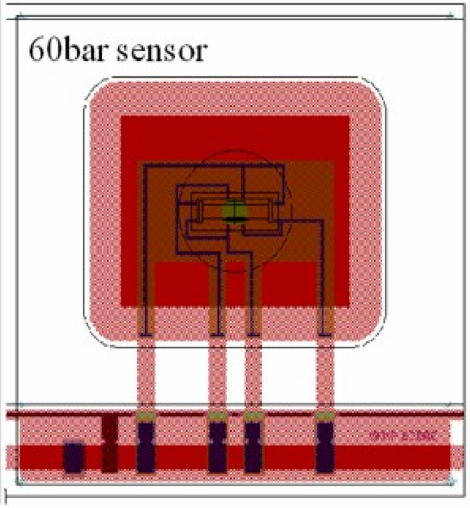


Micromachining equipment, SINTEF

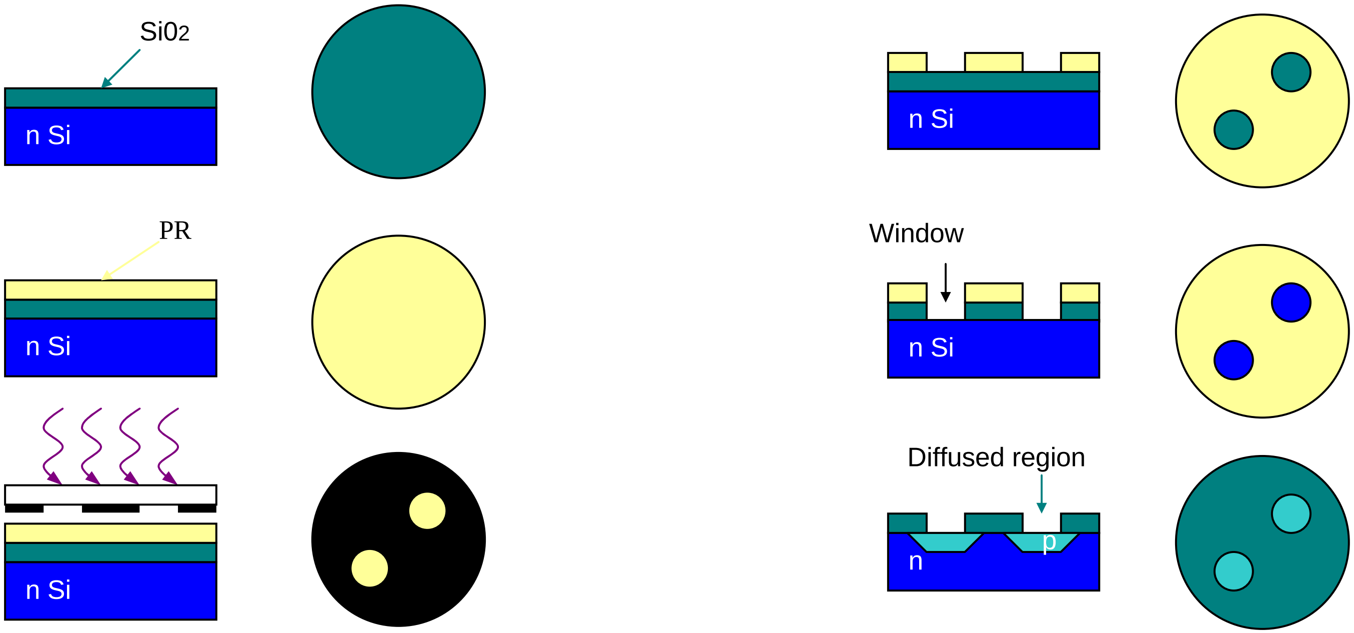
- Photolithography
- Furnaces for diffusion and oxidation
- ICP PECVD (deposition)
- Deep reactive ion etch
- Wet etch of silicon
- “Quick and dirty room”
- Silicon/glass wafer bonding
- Dicing
- Measurement lab + SEM

Layout of lithographic masks





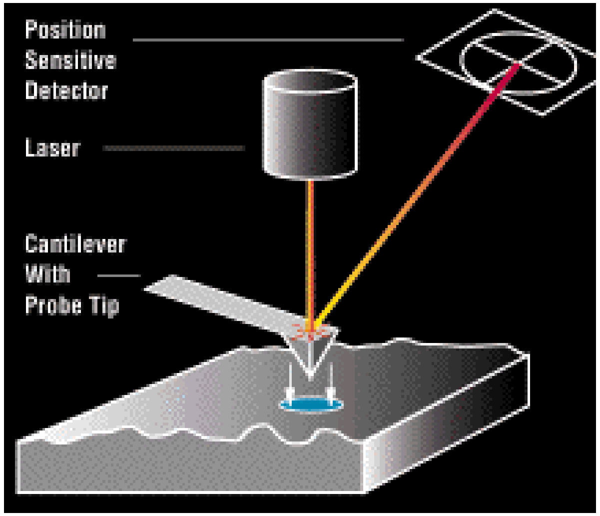
Fotolitografi
Mønsteroverføring fra maske til resistfilm på silisiumskive

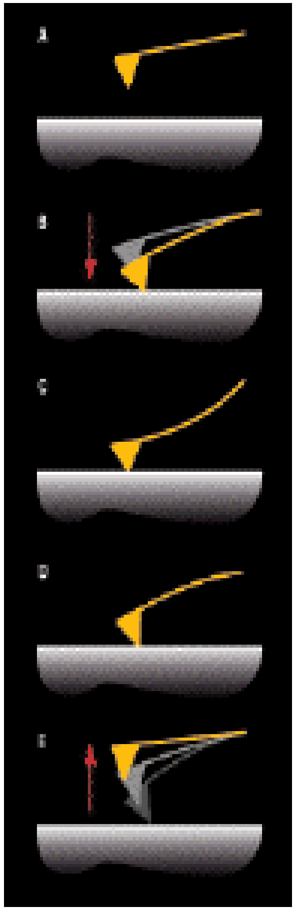


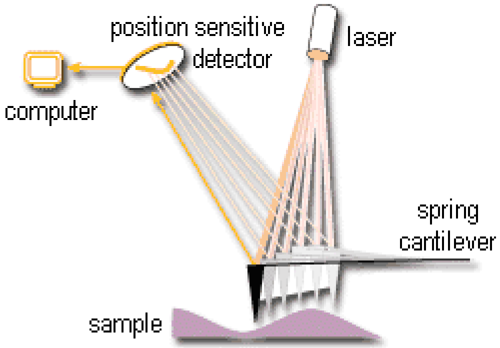
Beam example: Atomic Force Microscope

- 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







Translating biomolecular recognition into nanomechanics
Science 288, 2000

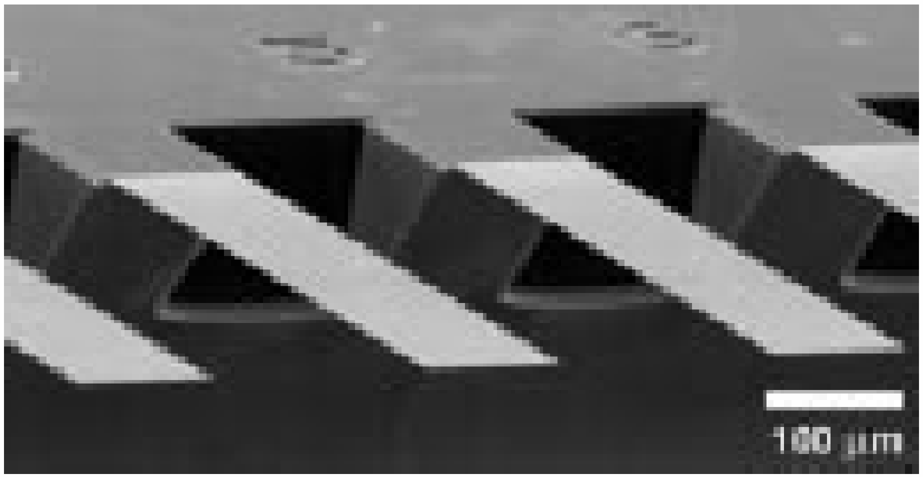


Fig. 1. Scanning electron micrograph of a section of a microfabricated silicon cantilever array (eight cantilevers, each 1 µm thick, 500 µm long, and 100 µm wide, with a pitch of 250 µm, spring constant 0.02 N m^{-1}; Micro- and Nanomechanics Group, IBM Zurich Research Laboratory, Switzerland).

Bulk silicon micromachining

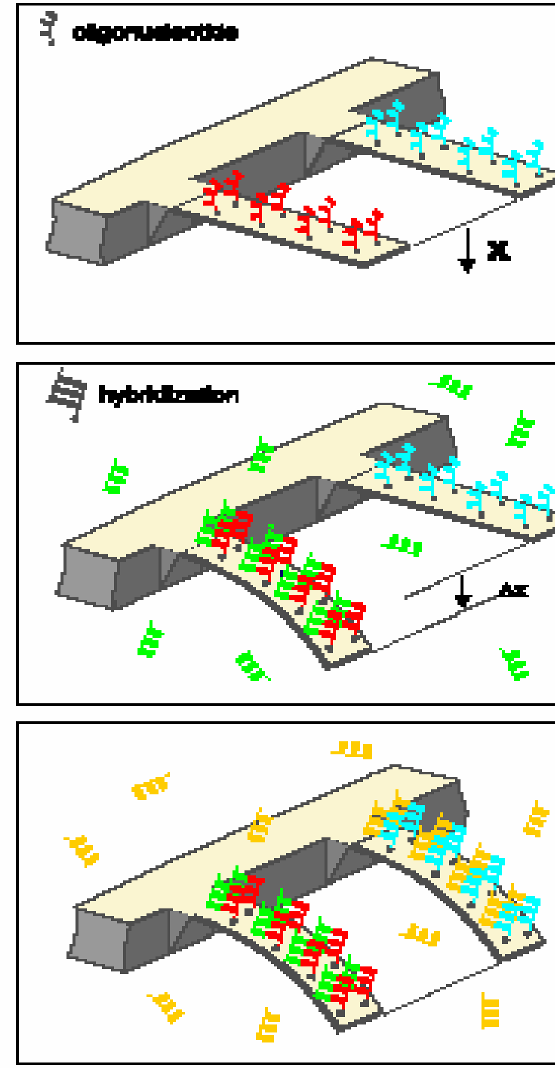
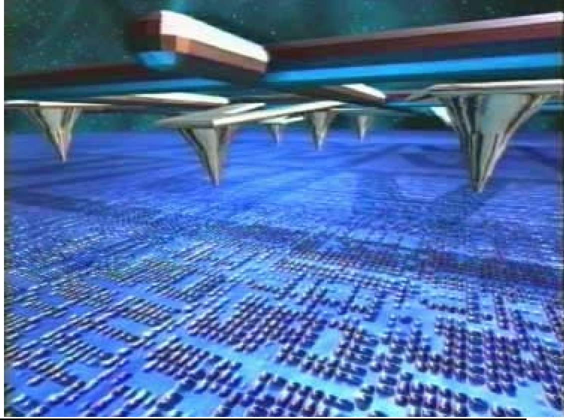


Fig. 2. Scheme illustrating the hybridiza
experiment. Each cantilever is functionalize
one side with a different oligonucleotide
sequence (red or blue). (A) The differe
signal is set to zero. (B) After injection of
first complementary oligonucleotide (gre
hybridization occurs on the cantilever that
vides 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.

Millipede, IBM Zurich



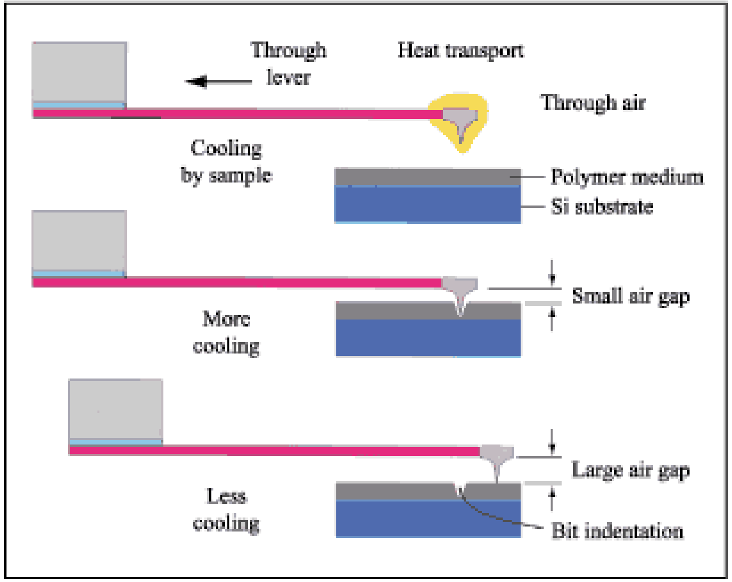


Figure 4

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.

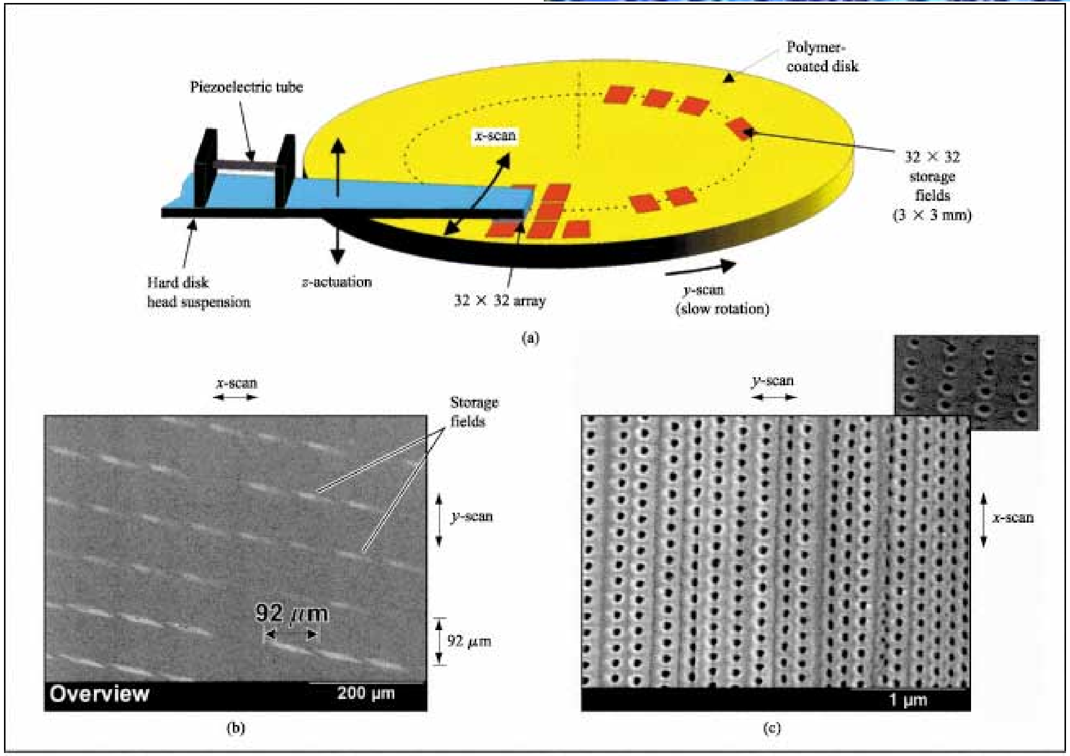


Figure 14

(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).

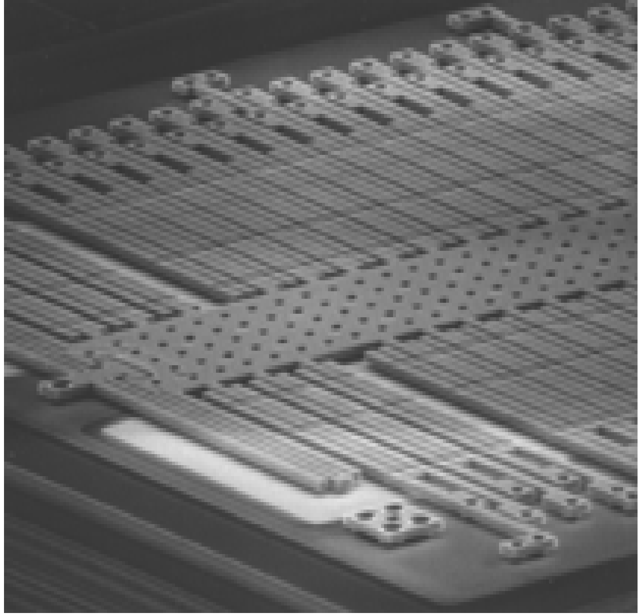
Capacitive surface comb-accelerometer

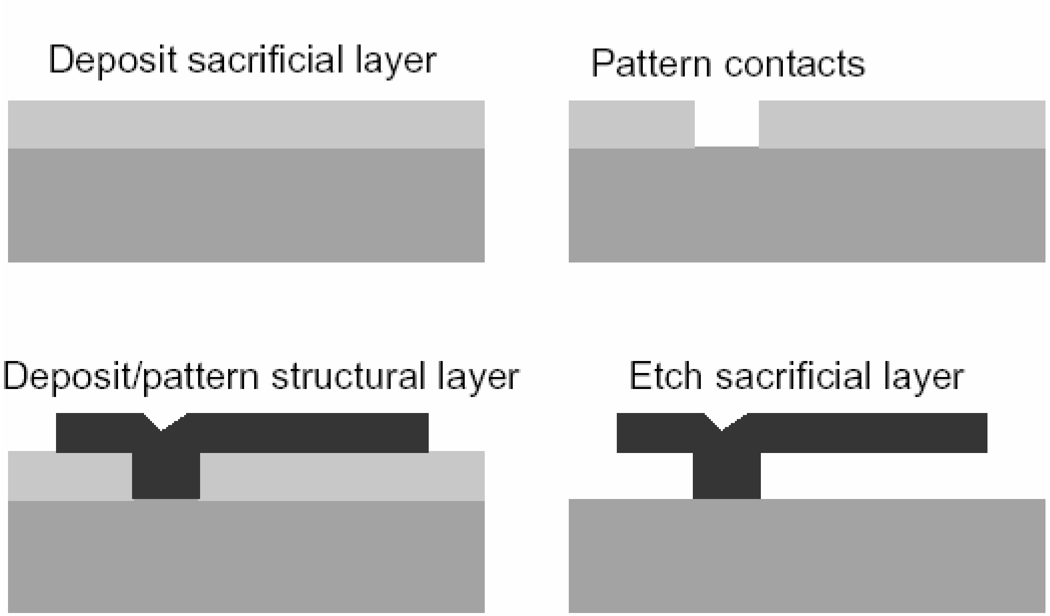
- Polysilicon
Surface micromachining

Design of:
- Low-g accelerometer (5g)
- Capacitive read-out: collaboration with microelectronics

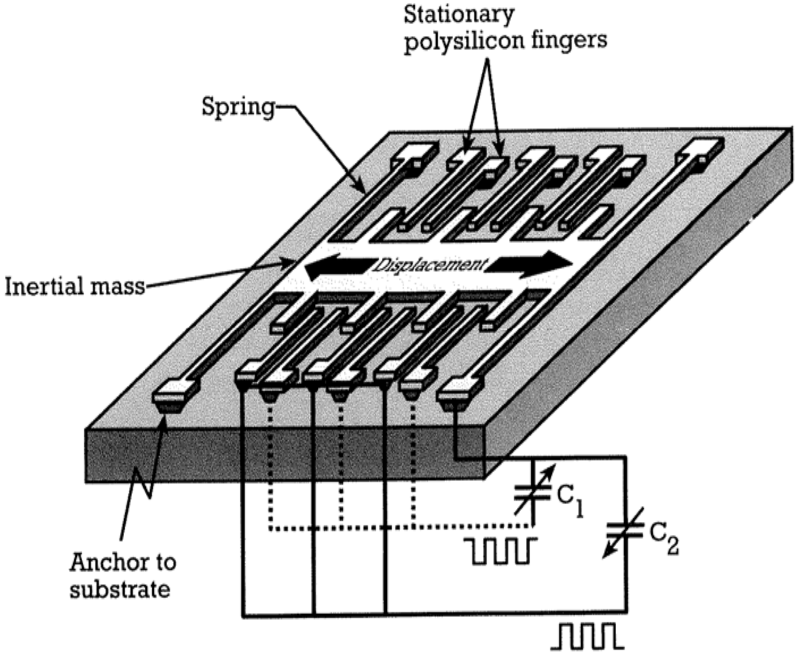
Self-test

Analog Devices





A Capacitive Accelerometer



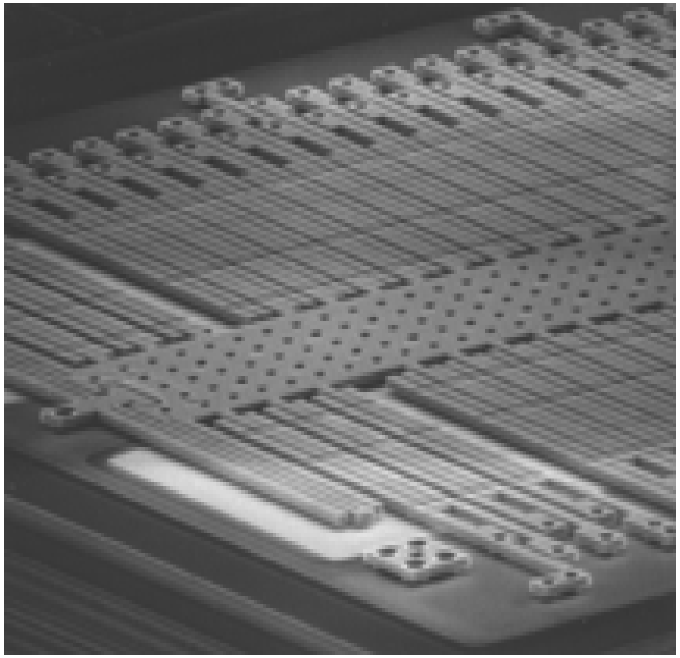
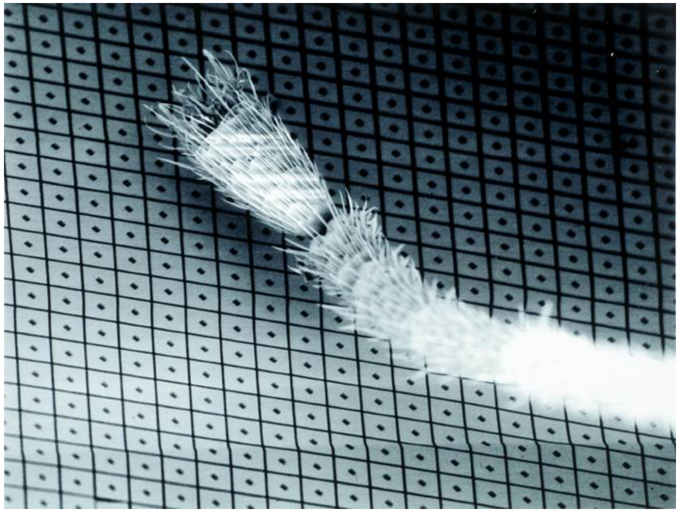
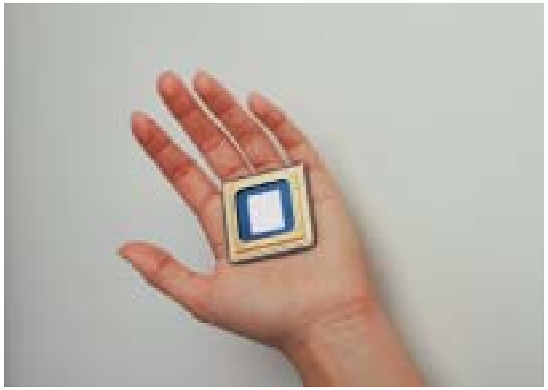


Image projector
with micromachined mirrors
Digital Light Processing, Texas Instruments

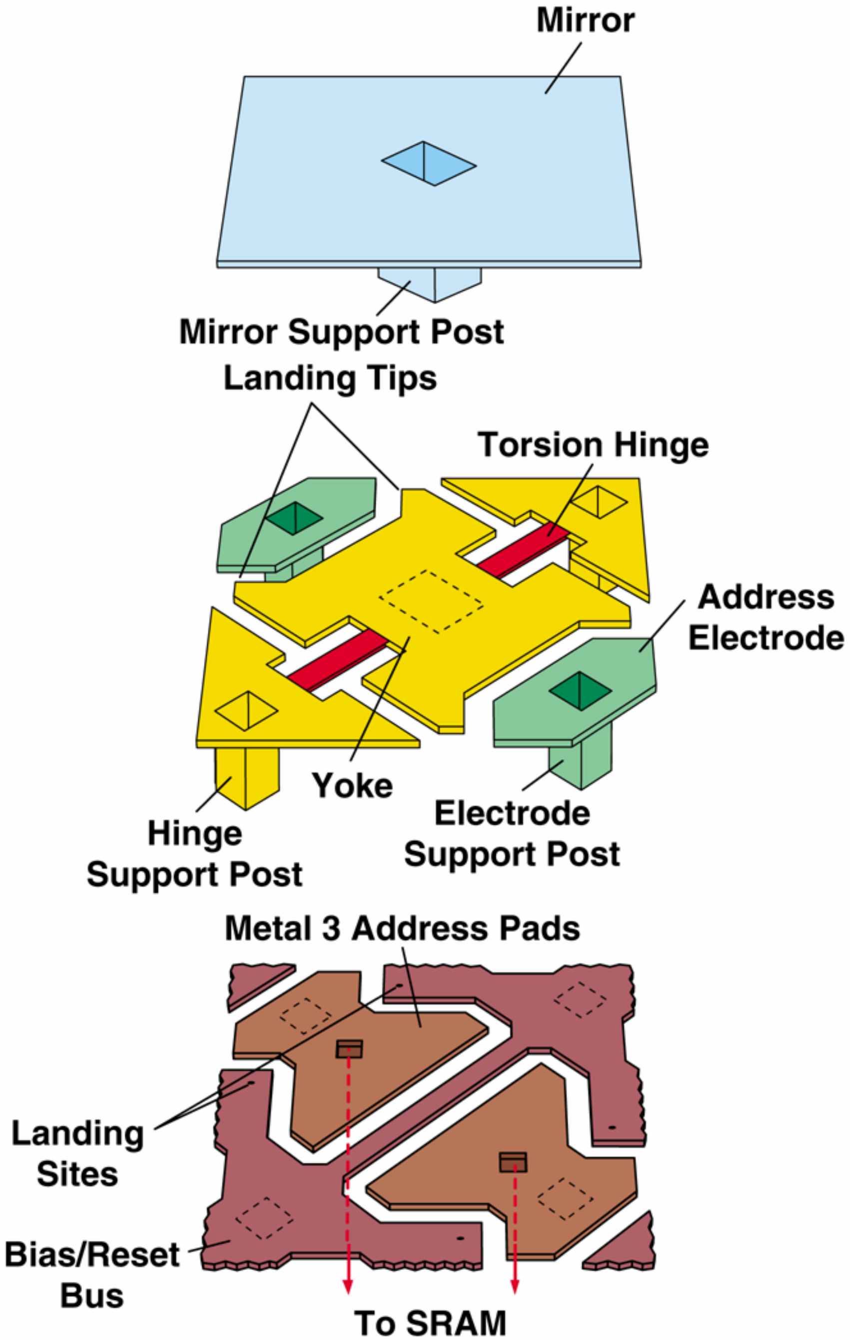


- Aluminium micromirrors fabricated on the surface of a silicon wafer with an integrated circuit
- Mirrors are individually controlled
- Size of mirror: 16μm x 16μm (?)
- Mirrors separated by 1μm
- One chip: 1920x1080 mirrors (2 073 600 mirrors)



One micromirror

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

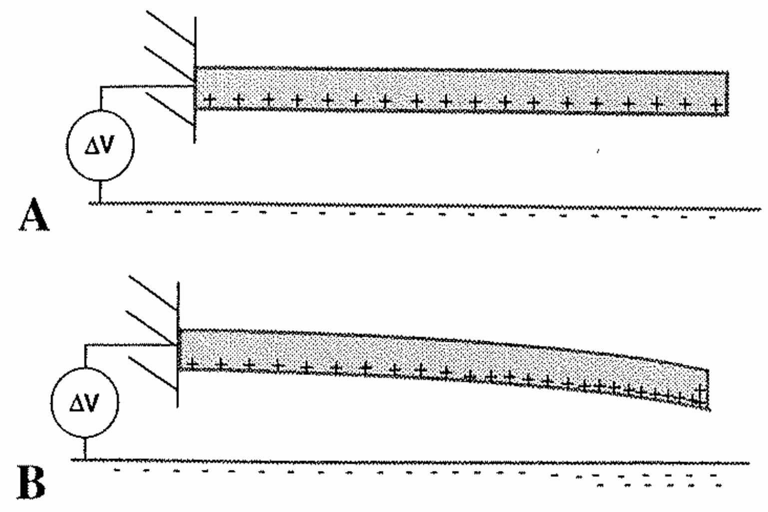


Electro-Mechanical behaviour

- 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

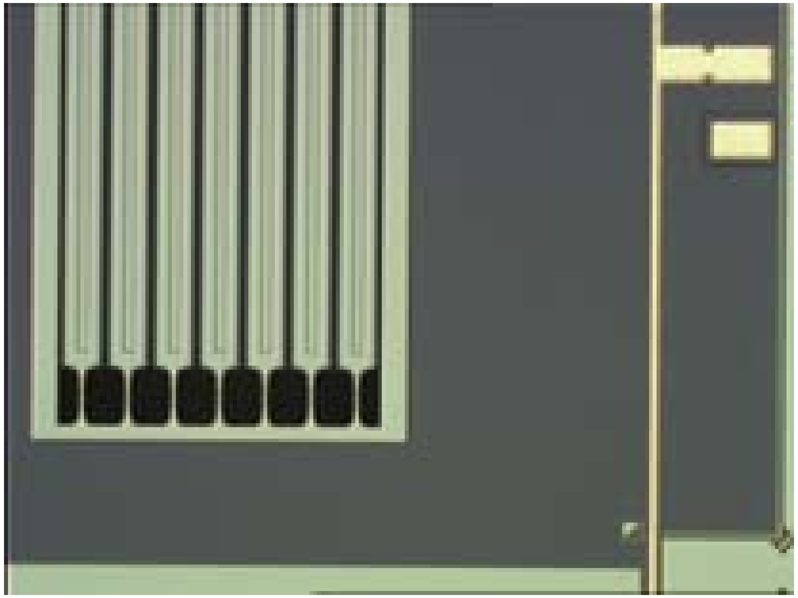
- Reynolds equation solved separately
- Viscous damping, film spring effect

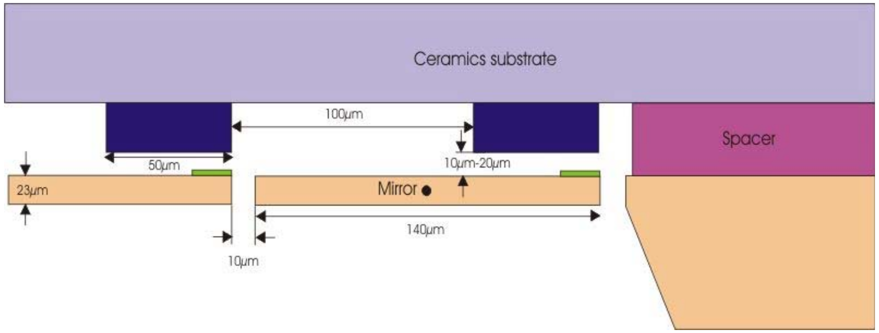
Bulk-micromachined mirror

MultiMEMS
Your multifunctional MEMS service

- Application: bar-code reader
- Electrostatic actuation
- Mirrors tilts
- Packaging: Tick film on ceramics (Microcomponent)

- Modellering: Multiphysics
  - Elasticity
  - Electro-statics
  - Fluidics

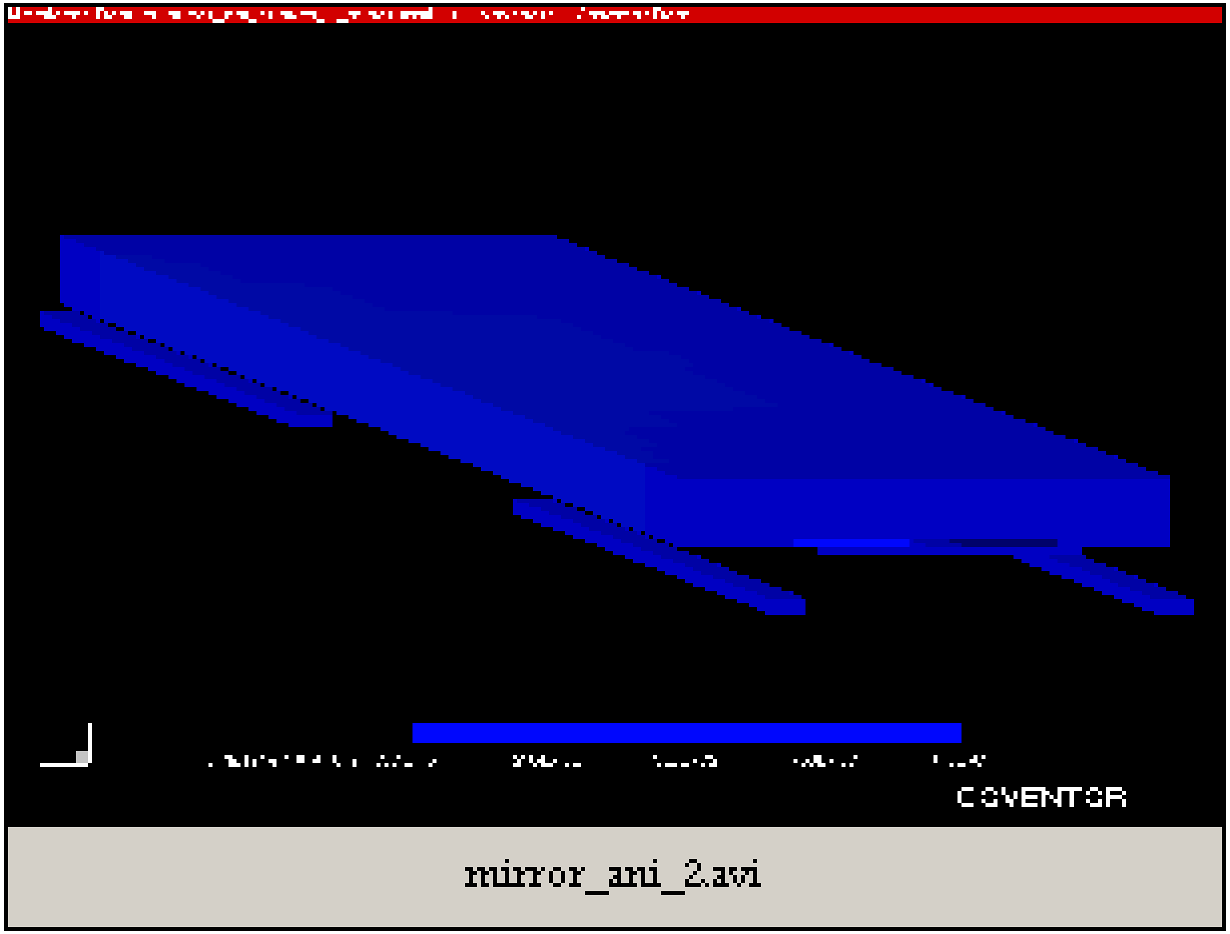




Parallel plate condensator ≈

$$F = -\frac{A\varepsilon\varepsilon_0}{2x^2}V^2$$

Coupled electrostatic-elastic simulation of mirror



Klaus Magnus Johansen, Oddvar Søråsen, Liv Furuberg, UiO

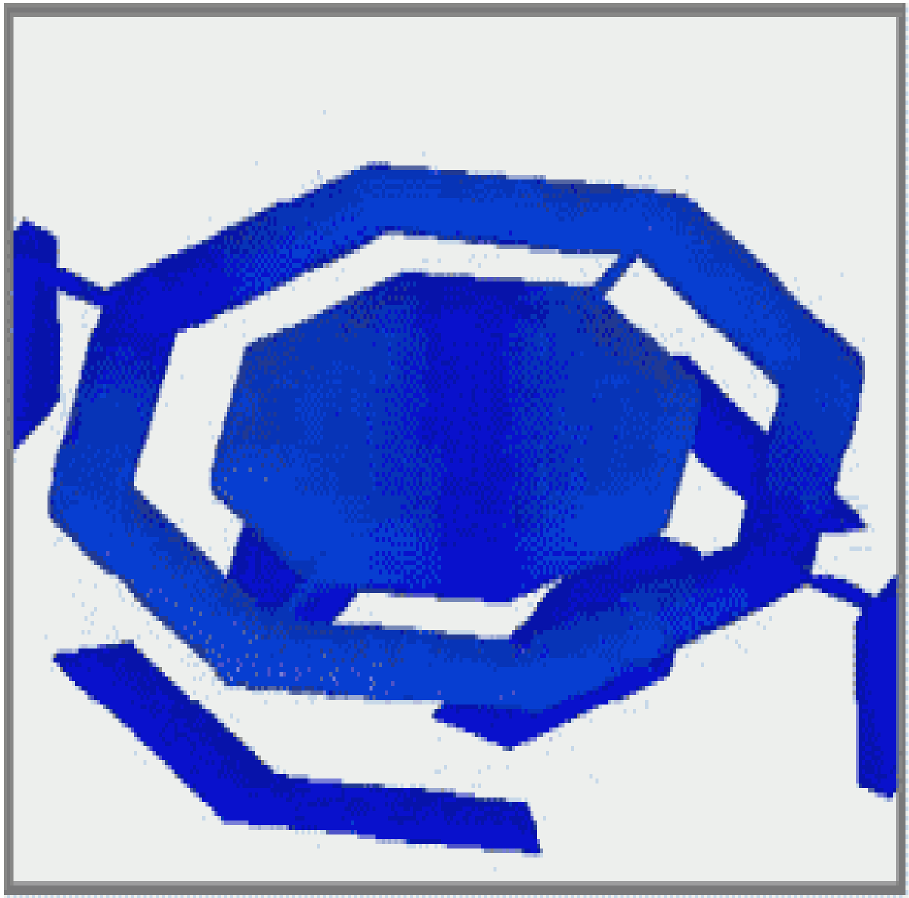
Mechanical and electrostatic equations

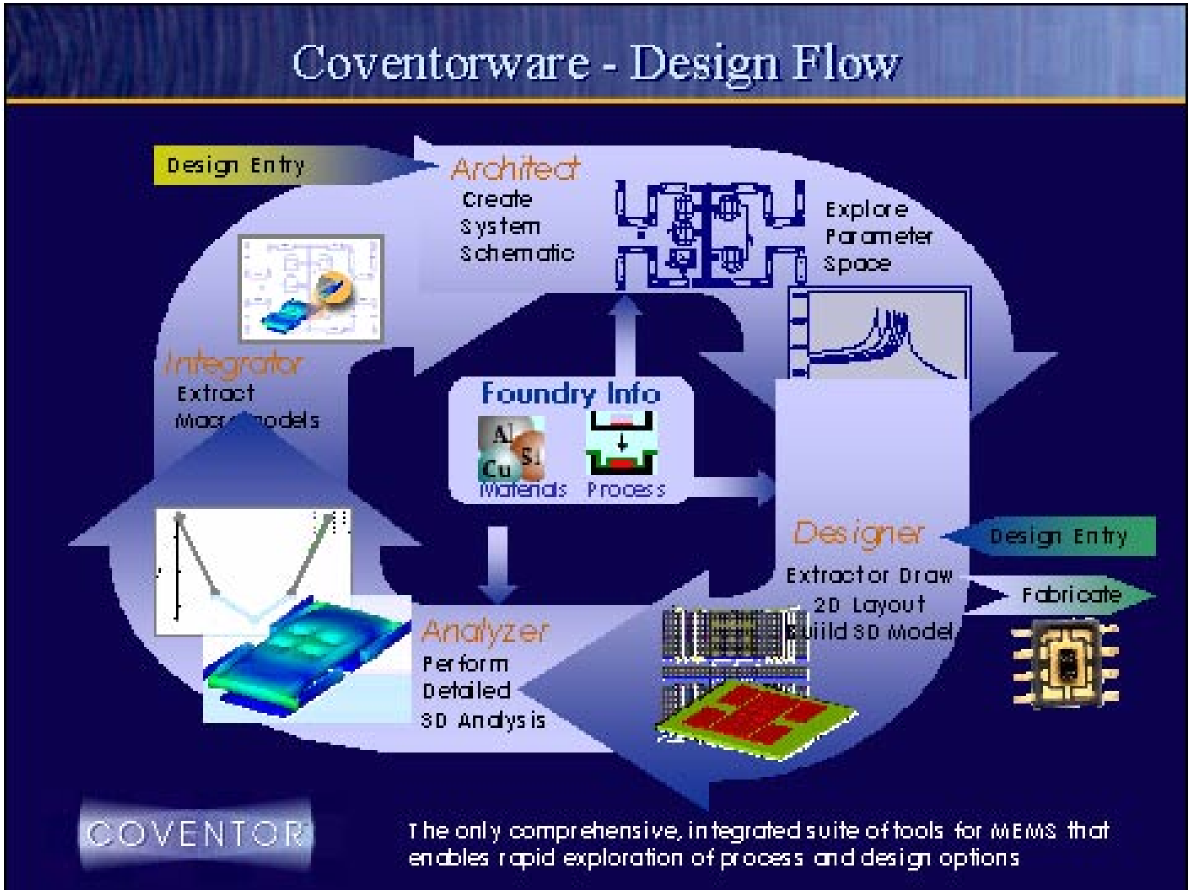
- Naviers equation for elastic forces: (isotropic version)

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

- Poisson equation for electrostatic field:

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





Coventorware - Design Flow
Design Entry
Architect
Create System Schematic
Explore Parameter Space
Integrator
Extract
Foundry Info
Al
Si
Cu
Materials
Process
Designer
Design Entry
Extract or Draw
2D Layout
Build 3D Model
Fabricate
Analyzer
Perform Detailed 3D Analysis
COVENTOR
The only comprehensive, integrated suite of tools for MEMS that enables rapid exploration of process and design options

Detailed modelling levels

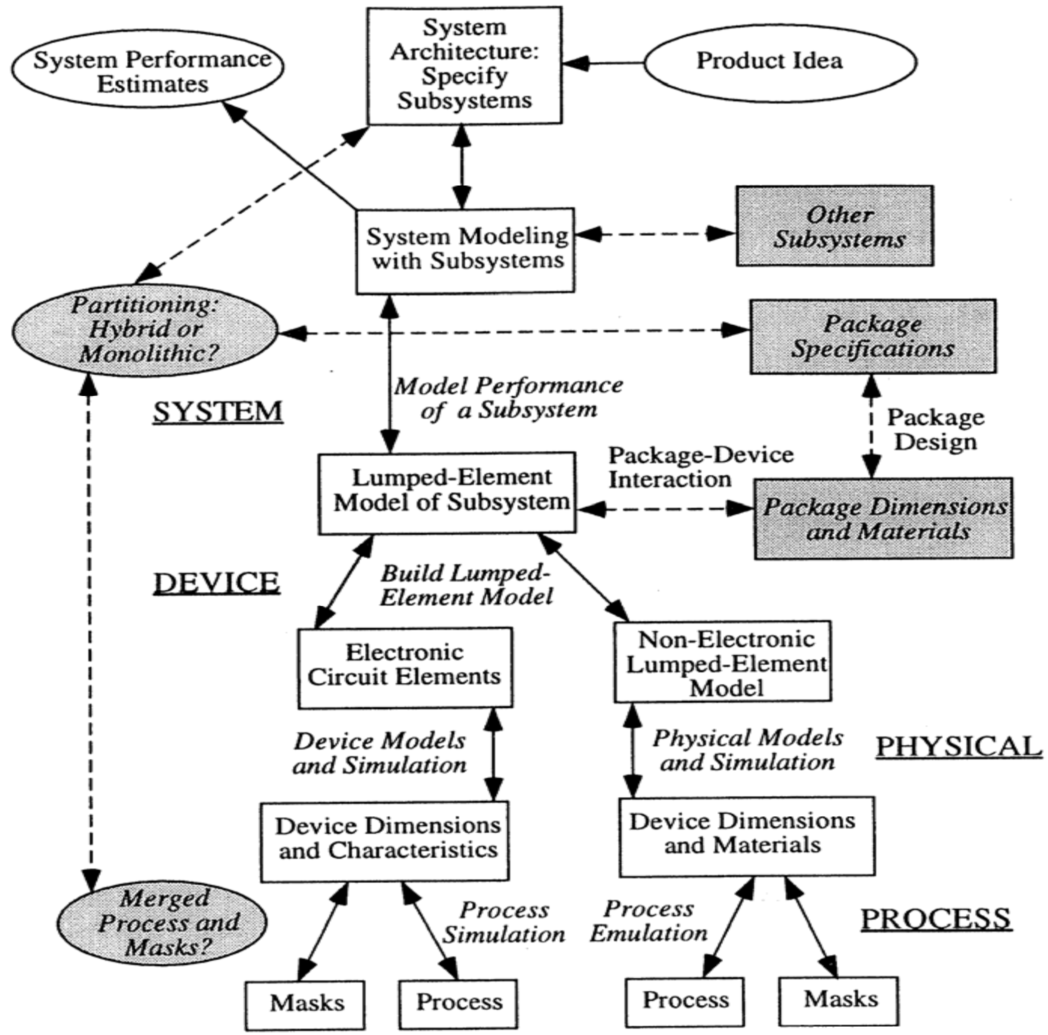
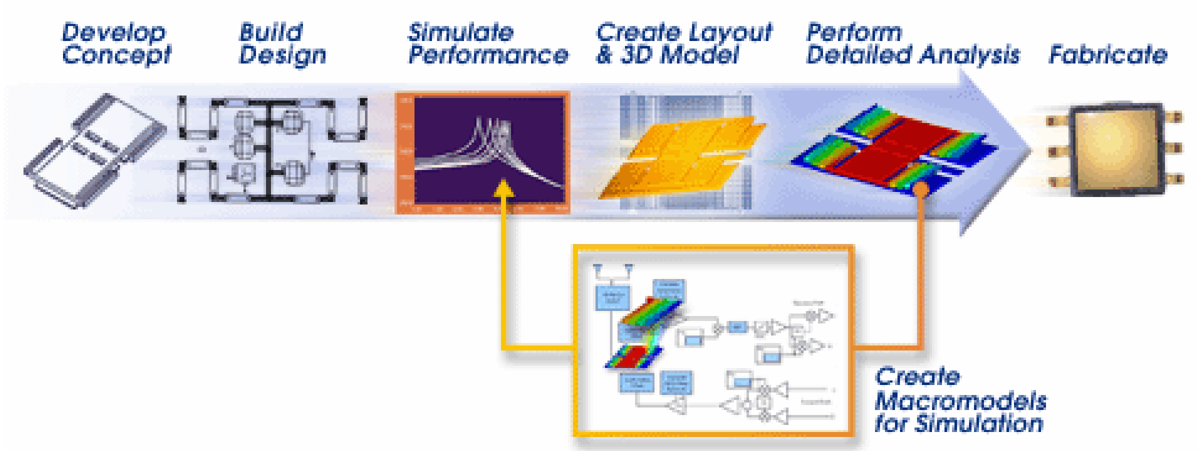
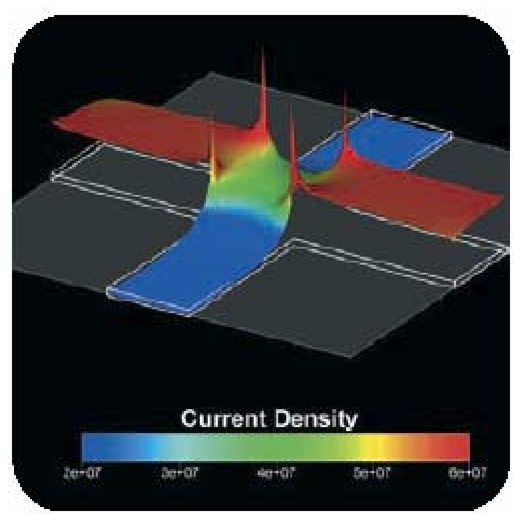


Figure 2.3. An expanded view of the "Modeling and Analysis" block of Fig. 2.1. The various modeling levels of Fig. 2.2 are indicated, and correspond to the entries in italics between the unshaded blocks. The shaded blocks are additional aspects of the design process not captured in Fig. 2.2.

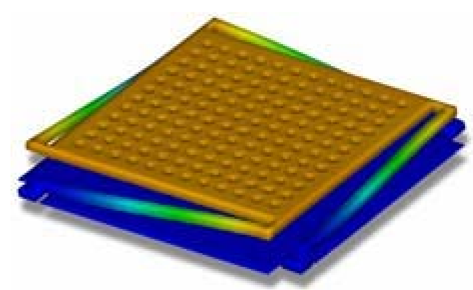
Coventorware ANALYZER

- Device modelling
- Continuum mechanics
- Electromagnetism
- Optics
- Piezoelectricity
- Piezoresistivity
- Fluidics



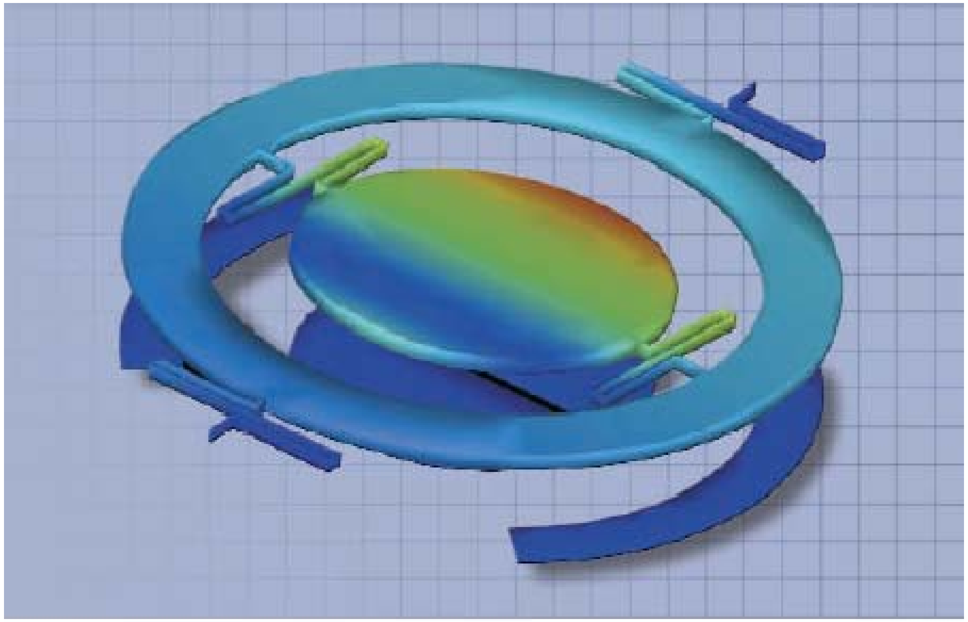


MemPZR analysis of a piezo-resistor cross



Coventorware
Microsystem modelling and layout

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



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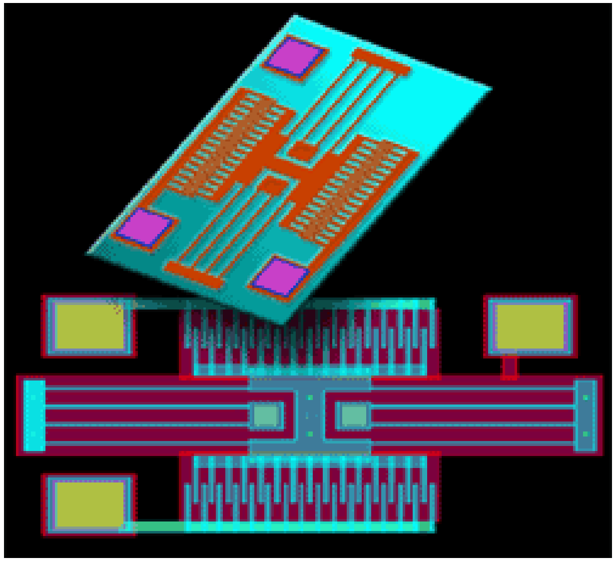
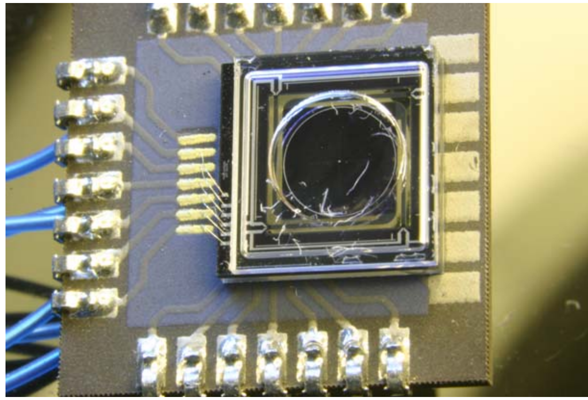
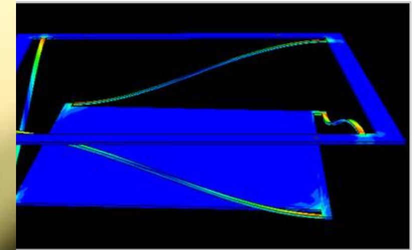


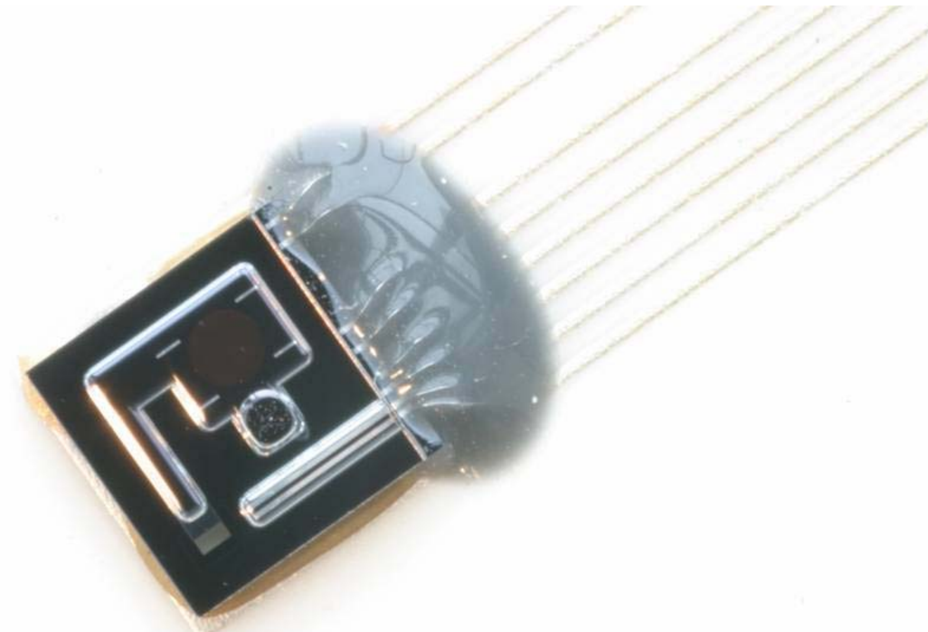
ist
information society technologies



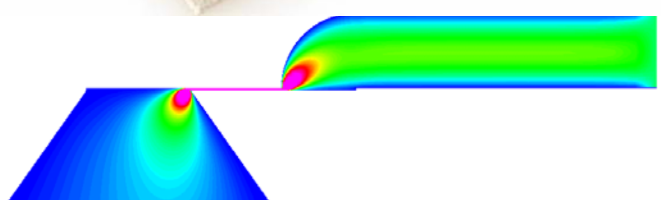


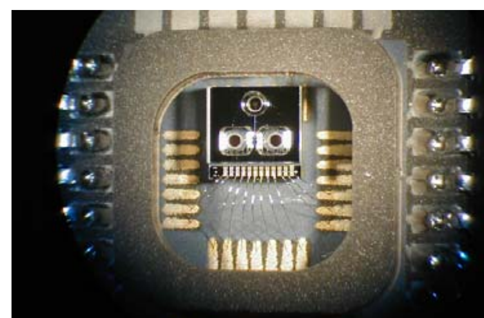
EUROPRACTICE

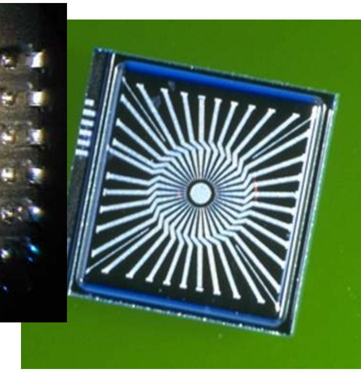
MultiMEMS
Your multifunctional MEMS service



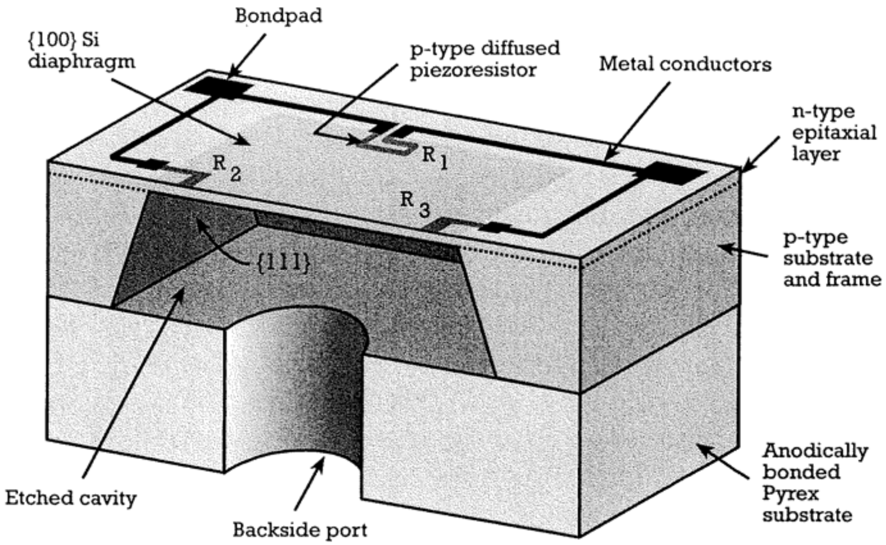
microBUILDER

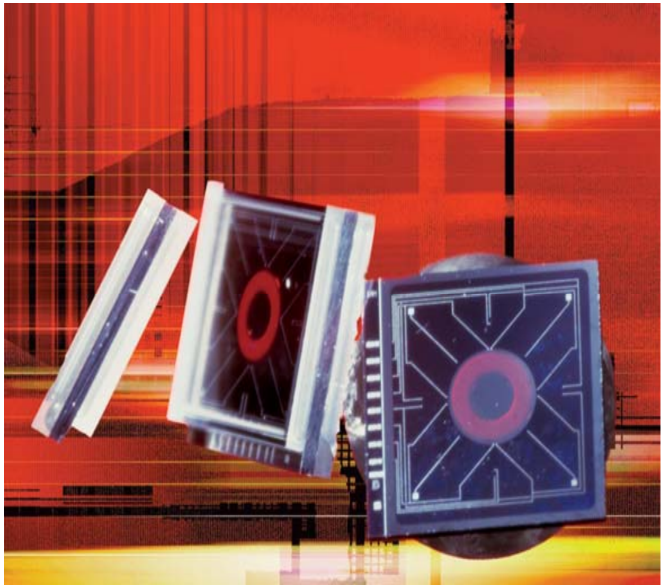


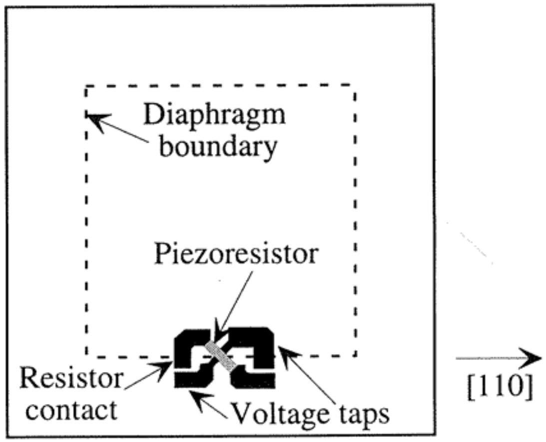




Piezoresistive pressure sensors







Mechanical modelling

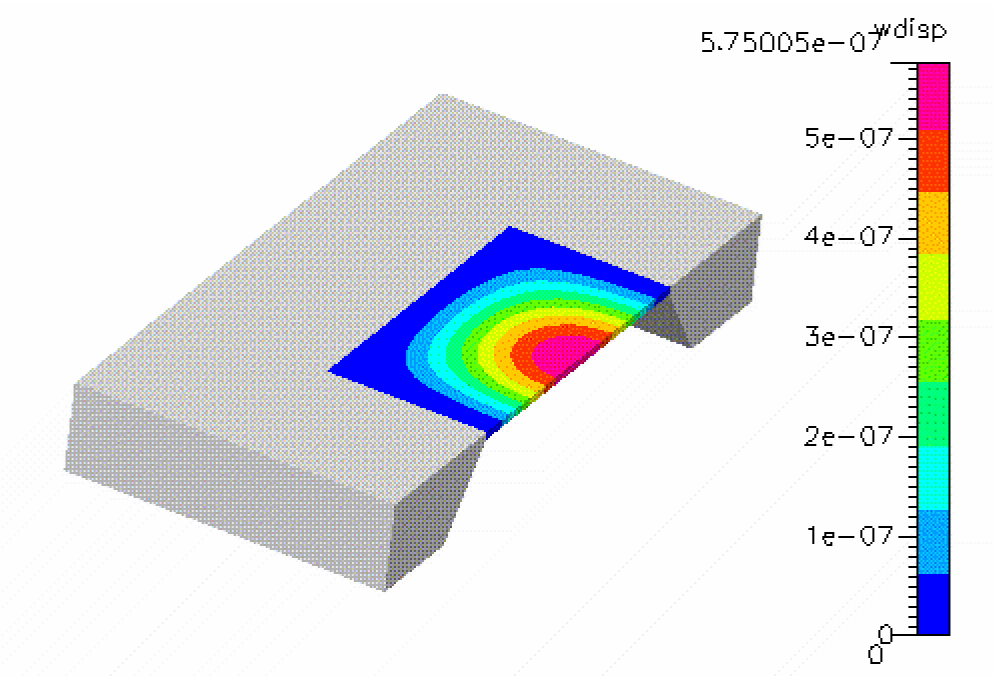
- Deflection of mechanical elements due to forces
- Stress in mechanical elements
- 3D elasticity equation, plate or beam equations
- Crystal silicon

Membrane etched in single crystal silicon:

•$E=1.698 \times 10^{11}$ N/m^2, v=0.066

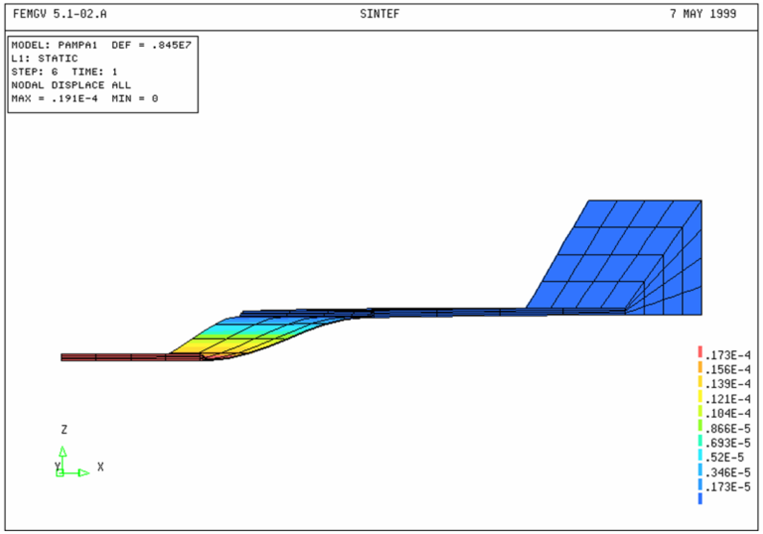
•Analytical solution Wmax=5.732×10^{-7}m

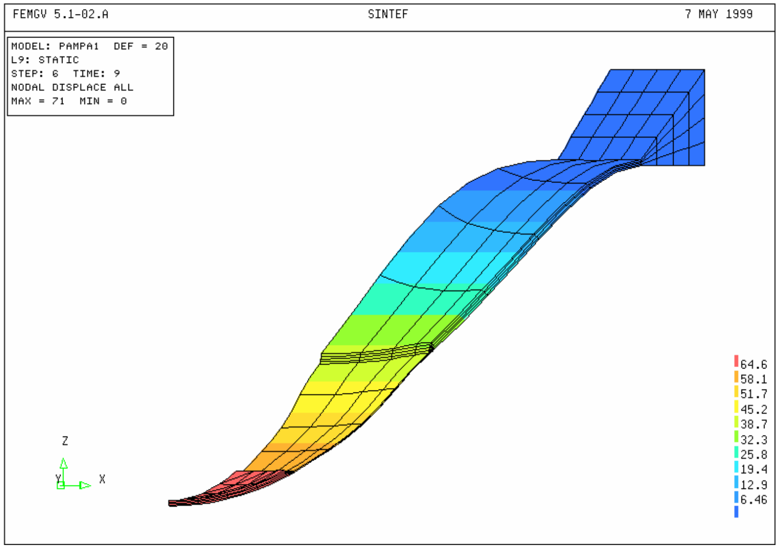
•Present prediction Wmax=5.750×10^{-7}m

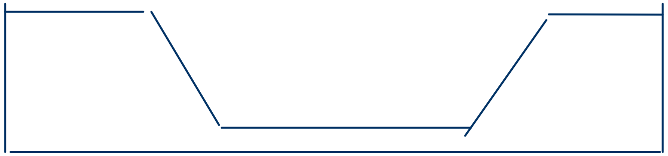


From compression to tension

- Turn membrane upside down
- Small pressures, thin membrane bends down, compression on lower side close to edges
- Large pressures, thick membrane bends down, thin membrane in state of tension

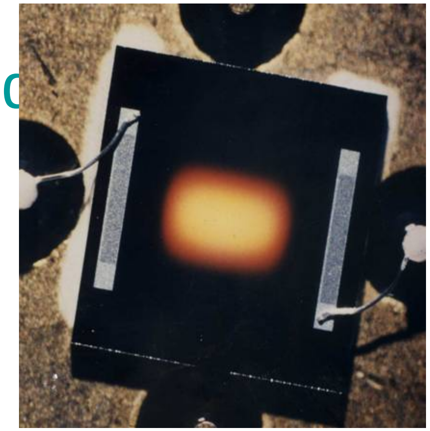


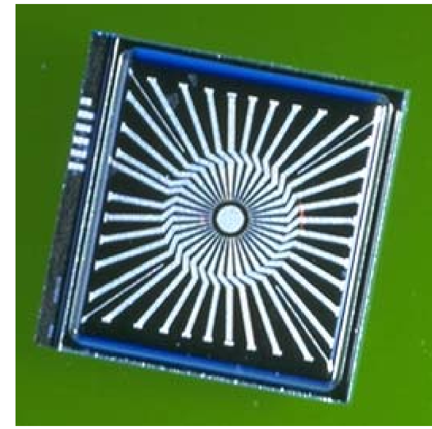


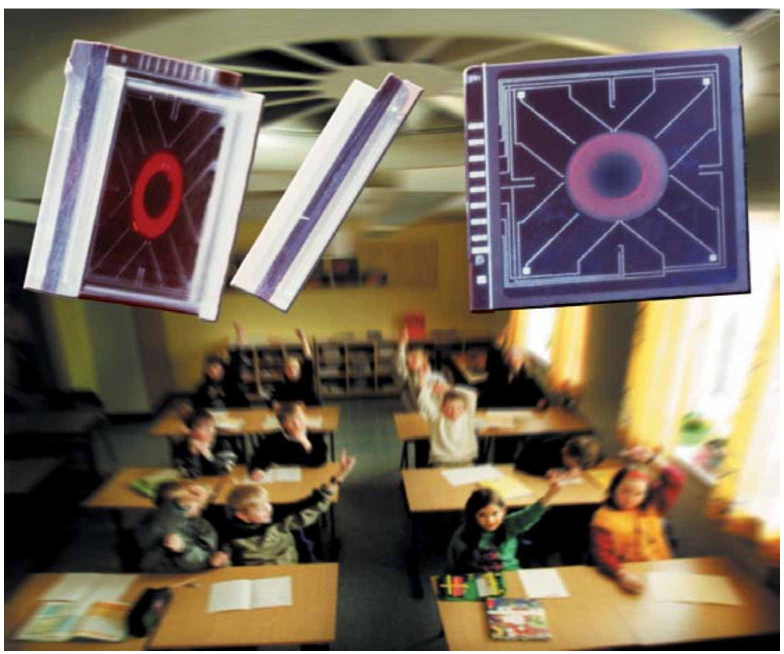


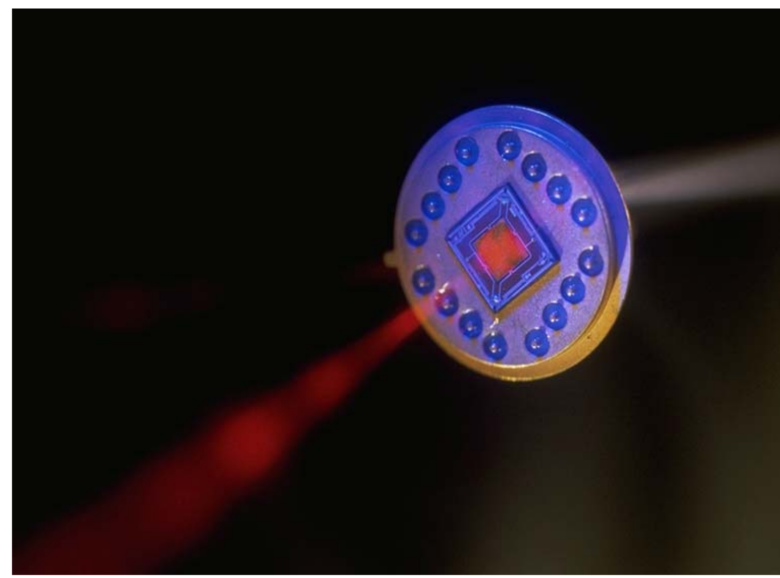
Photoacoustic gas sensor

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

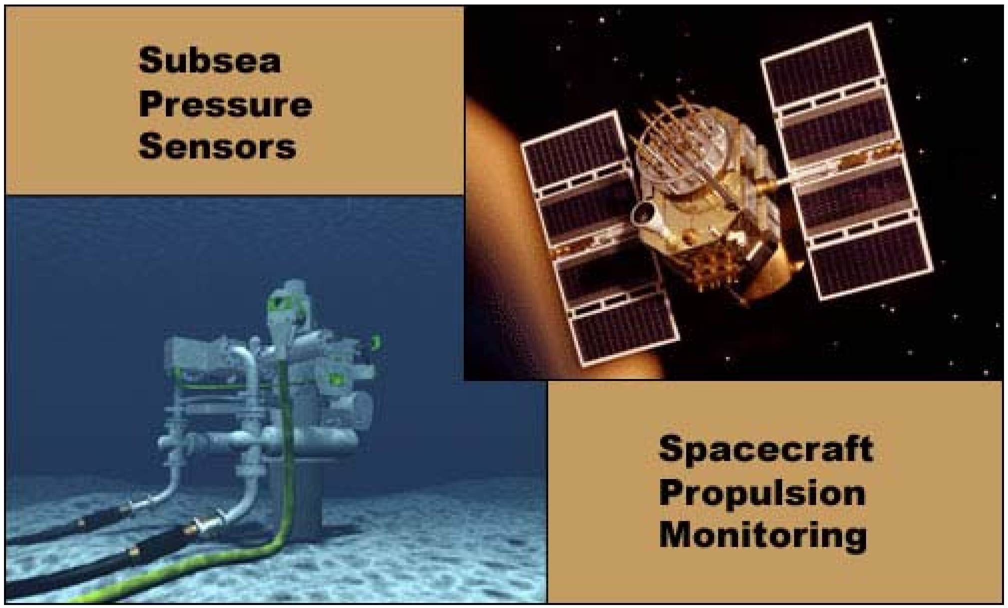


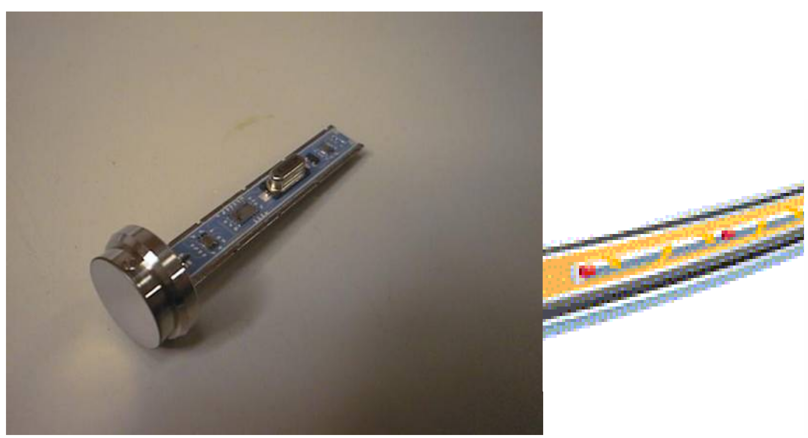






Trykksensor for høye trykk (2000 bar)
(Produseres i SINTEFs lab)





PRESENS

STATE OF THE ART SENSOR SOLUTIONS

Subsea oil well instrumentation

Flow from different zones of an oil reservoir is controlled by an integrated well control system

Requirements:

- **1000 bar, 180 C**

Monitor

- **Pressure**
- **Flow**
- **Fluid composition**
- **Temperature**

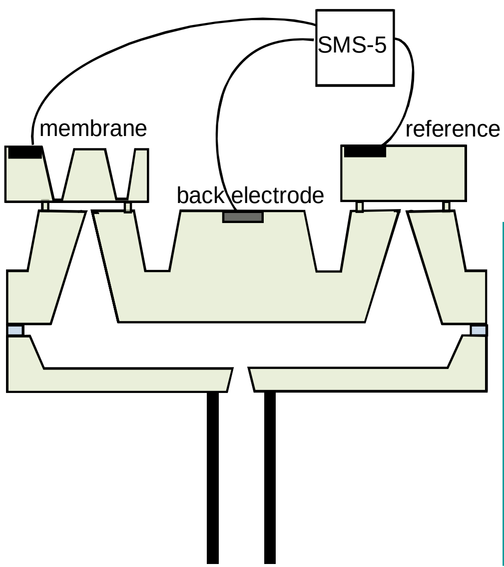
$$C = \frac{A\varepsilon\varepsilon_0}{x}$$

SINTEF: Interdisciplinarity!

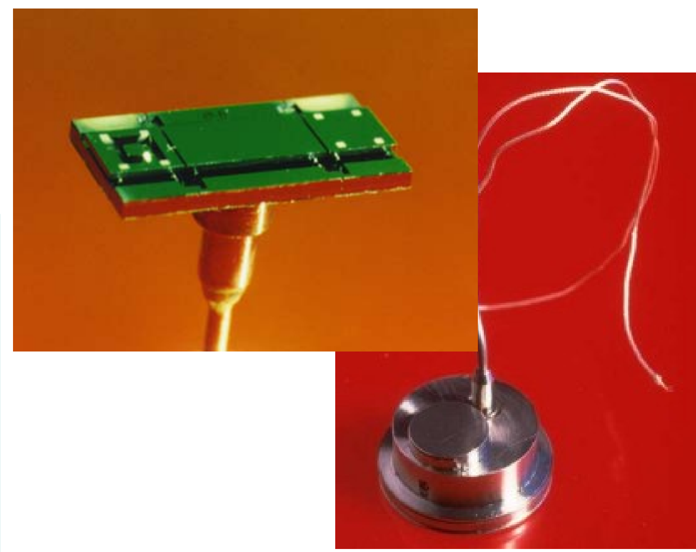
- **Design, fabrication and testing of**
  - **entire "fish"**
  - **diff. p sensor for flow meas.**
- **Design/test of HT-ASIC electronics**

PreSens:

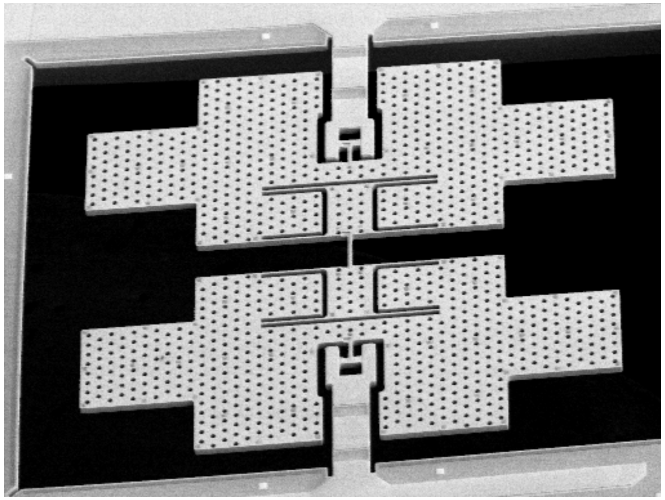
- **Absolute p sensor**

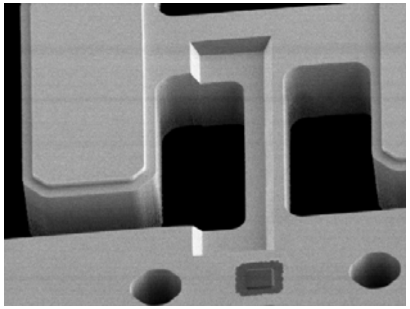


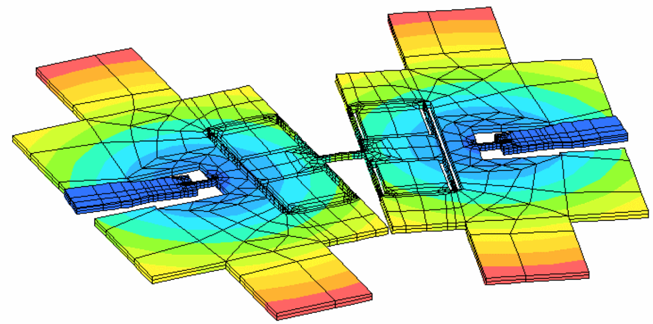
- **Capacitive sensing element**
- **3-stack fusion bonding (high-T)**
  - **Low zero shift vs. T and p**
  - **Low noise**
  - **High long term stability**

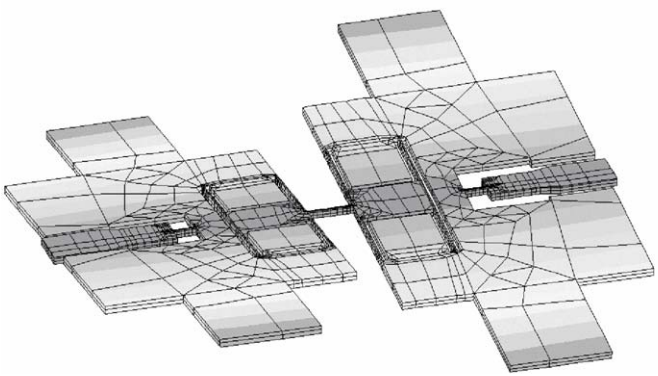


Capacitive roll-over sensor: SensoNor's SAR10



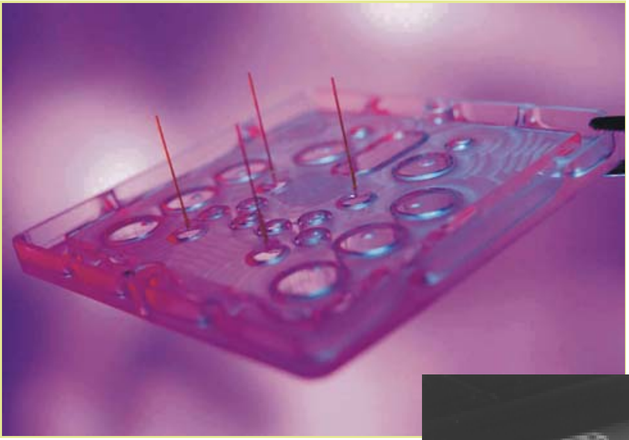




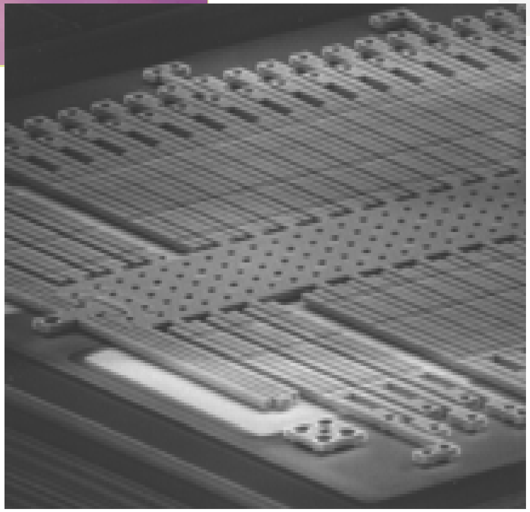


Course contents, 4 main “cases”:

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

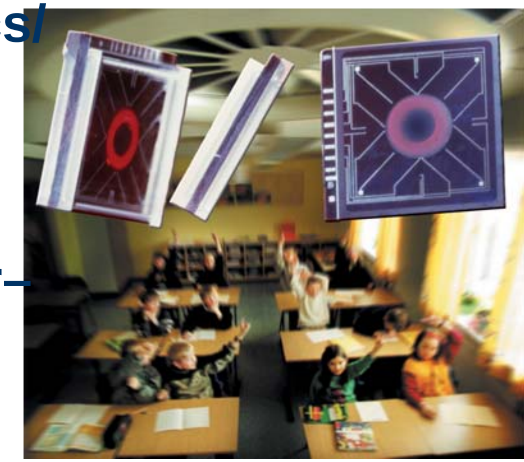


PCR analysis – microfluidics



Accelerometer – Inertial forces

Projector – optics/mechanics/ electrostatic



Pressure sensor– elasticity/ electronics

Uke	Dato	Tema	Litteratur
35	25/8	Oversikt over kurset, eksempler på mikrosystemer og modellering Mikromaskinering	Kapittel 1 +2 i Senturia Kapittel 3.1, deler av 3.2 og 3.3 Liv + Dag Wang
36	2/9	Silisium Elastisitetsteori Bjelker, elastiske strukturer	Kapittel 8.1, 8.2, 8.4, 8.5 Kapittel 9.1, 9.3, 9.5 Liv
37	9/9	Piezoresistiv sensor Oppgave	Kapittel 18 (ikke 18.3.1, 18.3.4) Dag Wang
38	16/9	Kapasitivt akselerometer	Kapittel 19 (ikke 19.3, 19.4.3) Dag Wang
39	23/9	Lumped modelling How to use Coventorware www.coventor.com Første Coventorware oppgave startes, Skal leveres 15/10	Fra kapittel 5 Dag Wang + Akbar Ali Khan
40	30/9	Besøk på SINTEF Microsystems manufacturing laboratory Møt opp i Gaustadalleen 23, ved siden av IFI. Øvre inngang, vestsiden av bygget.	Kapittel 3.1, deler av 3.2 og 3.3 Niels Peter Østbø
41	7/10	microBUILDER kurs	Kapittel 3.1, deler av 3.2 og 3.3 Christopher Grinde
42	14/10	Koblede elastiske-elektrostatiske systemer, pull in	Noe fra kap 6 Liv