Nano Environment Monitoring Unit for Space Applications

Presentation of initial concepts and ideas

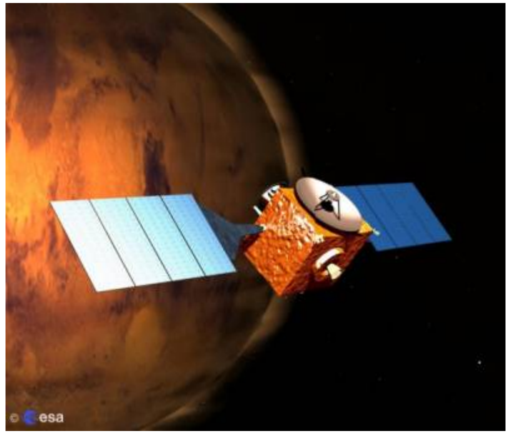
Jan H. Hales, M.Sc.E.E
Bioprobe Group
MIC – Department of Micro and Nanotechnology
Technical University of Denmark

Contents

- The envisioned capabilities of the system
- Technology background
  - – Activities in the Bioprobe group at MIC
- Initial design and concept of the proposed system
- Main issues
- Status & outlook

NEMU
Nano Environment Monitoring Unit

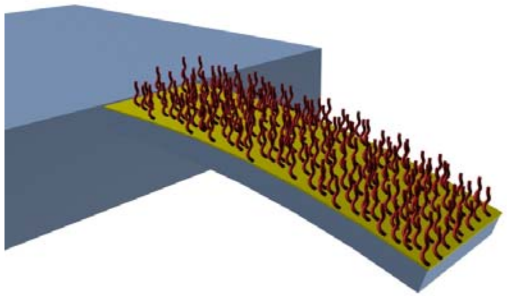
System enabling optimisation of robotic and human exploration by:



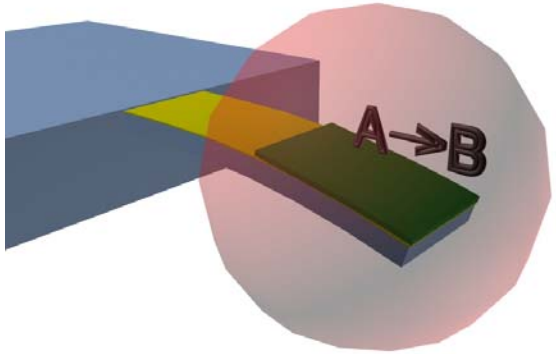
1. Analysis of dust particles
   - Especially in a Martian environment
2. Radiation monitoring
3. Detection/determination of specific vapors/gasses
4. Flow rates in liquids and gasses
5. Temperature profiles

Cantilever Sensors

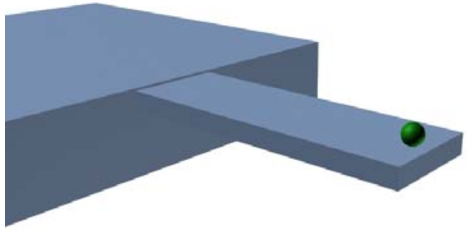
Static Mode | **Dynamic Mode**



Change of surface stress



Change of temperature



Change of mass

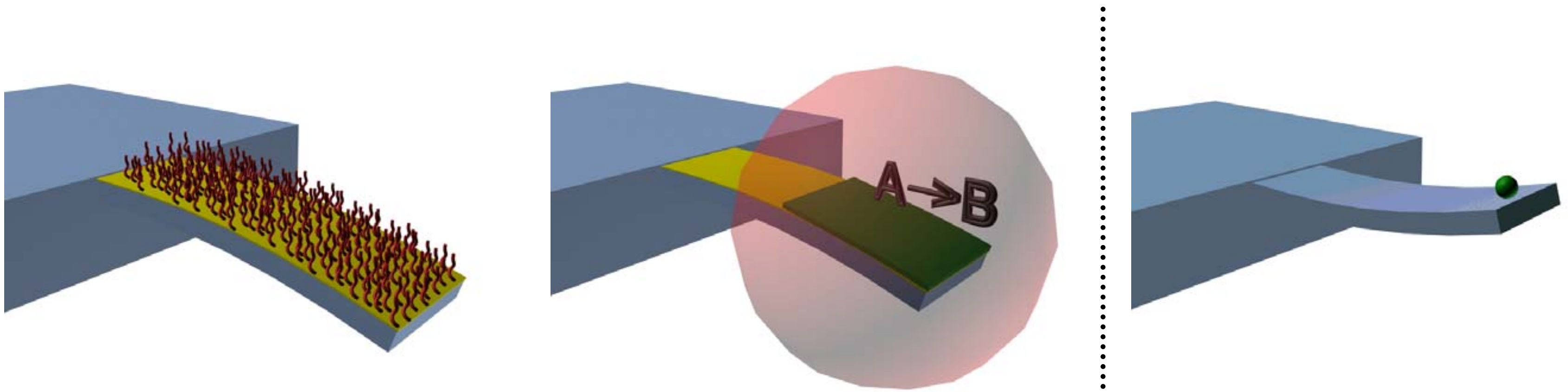
Gene/Protein detection

Antigen/antibody recognition

Gas detection

Cantilever Sensors

Static Mode | **Dynamic Mode**



Change of surface stress

Change of temperature

Change of mass

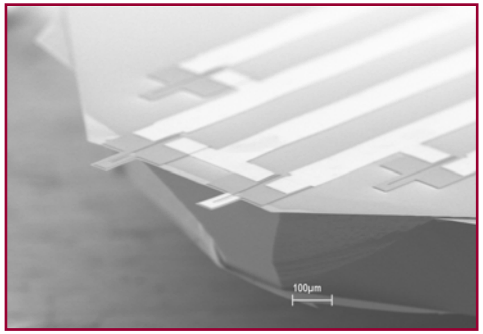
Gene/Protein detection

Antigen/antibody recognition

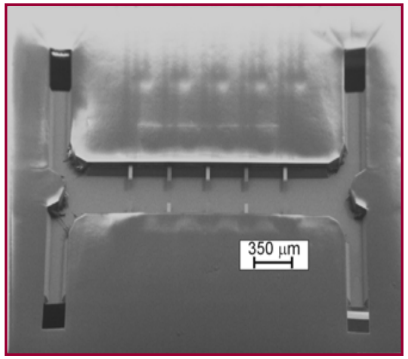
Gas detection

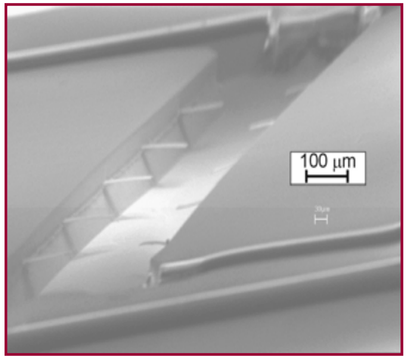
Bioprobe Technology

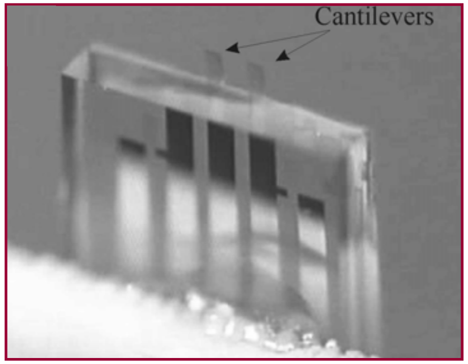
2-cantilever Si chip



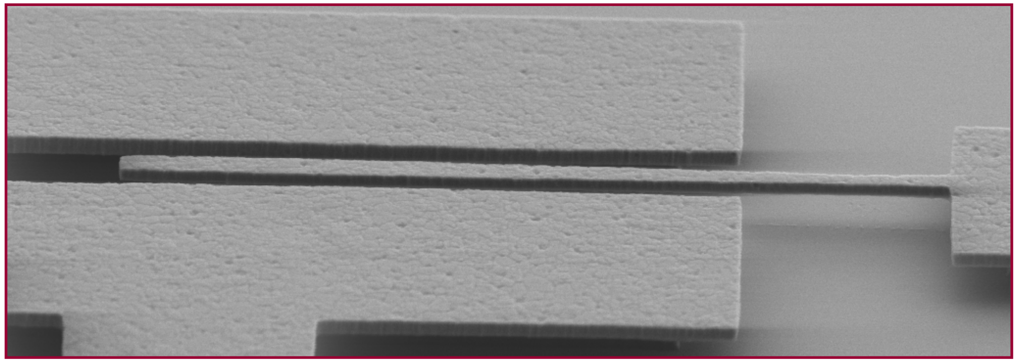
10-cantilever Si chip





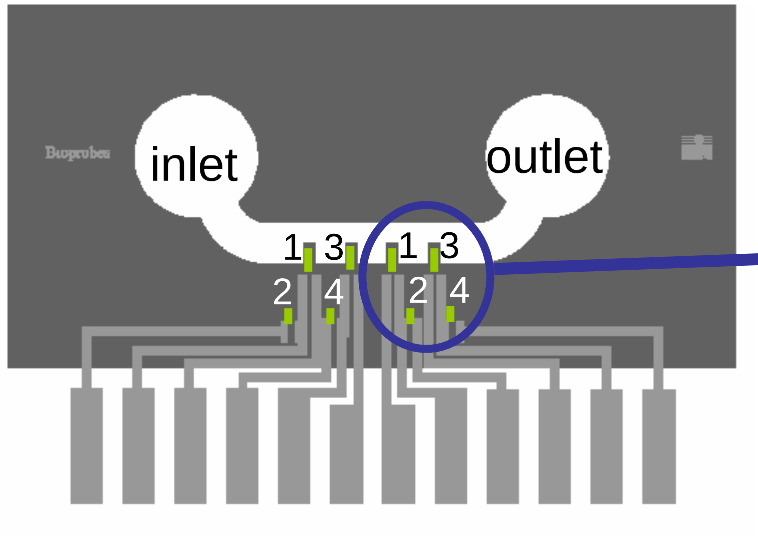


Polymer cantilever



Nanocantilever for mass detection

Chip Design



Cantilevers

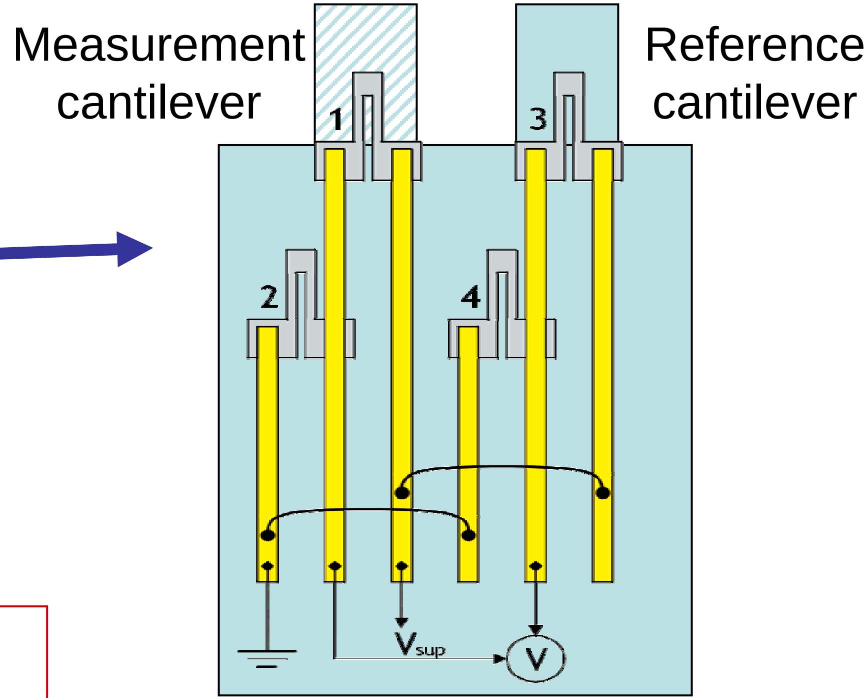
Thickness = 6 μm

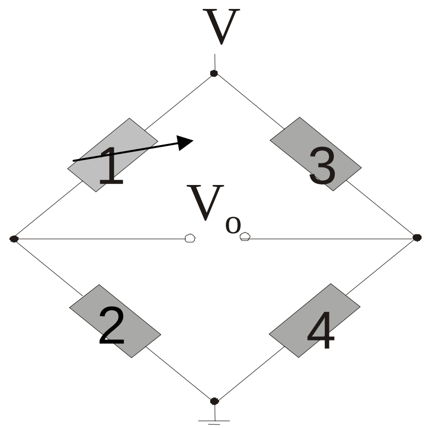
Width =100 μm

Length = 200 μm

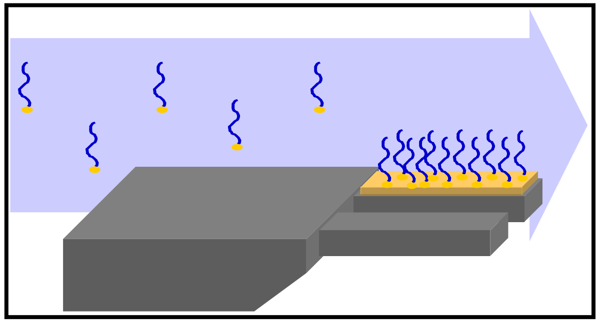
k = 4 N/m

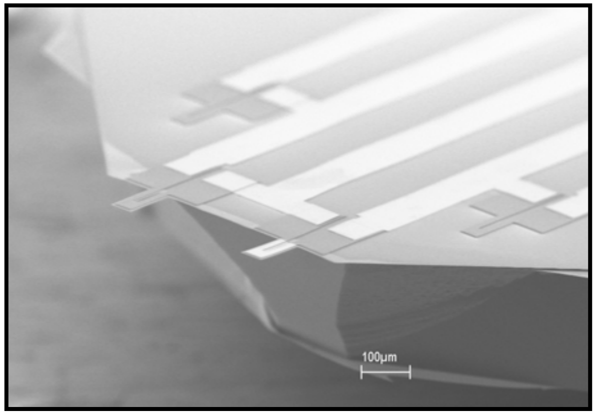
f_0 = 57 kHz

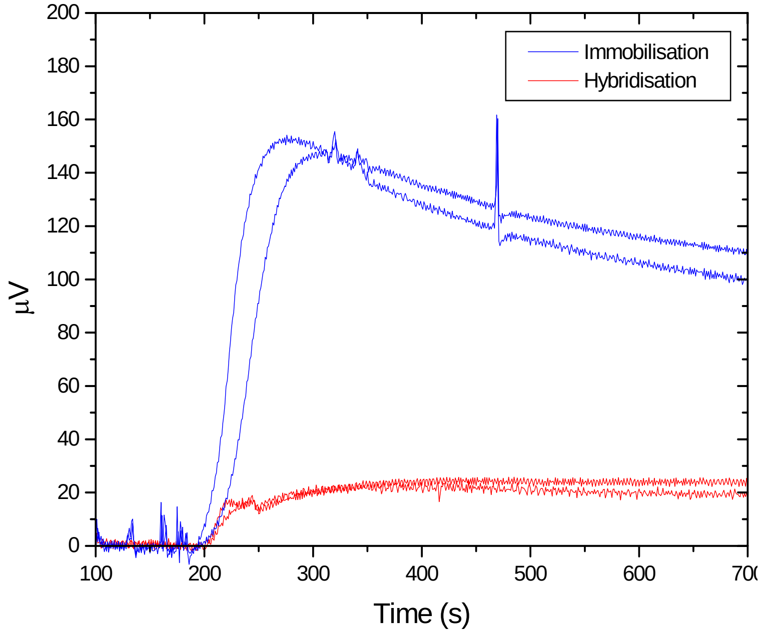




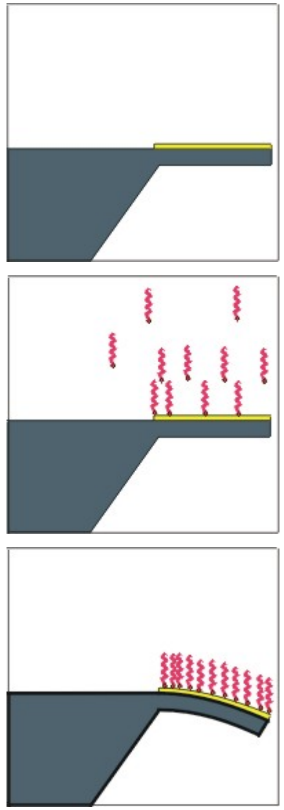
Biochemical Detection - DNA Detection





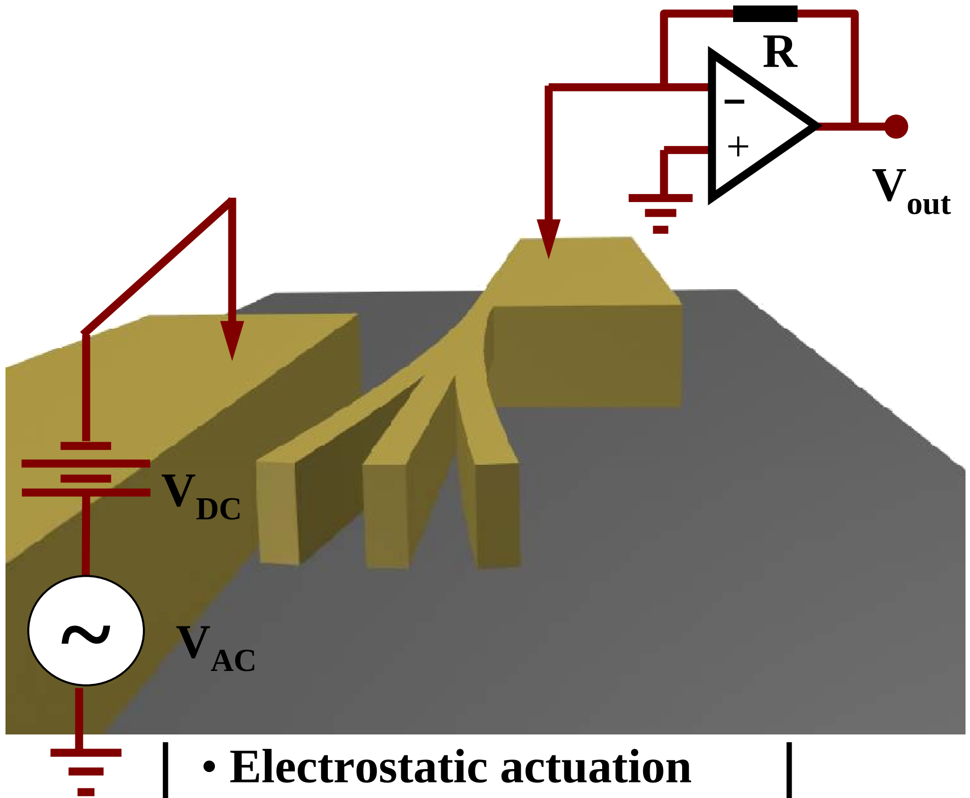


Rodolphe Marie and Cantion A/S



- Functioning as an electronic nose
- Detection of various chemicals in vapor phase
- Detection through calorimetric information

Resonating Cantilever - Dynamic mode



- Electrostatic actuation
- Capacitive read-out

CMOS integration

High Mass Sensitivity

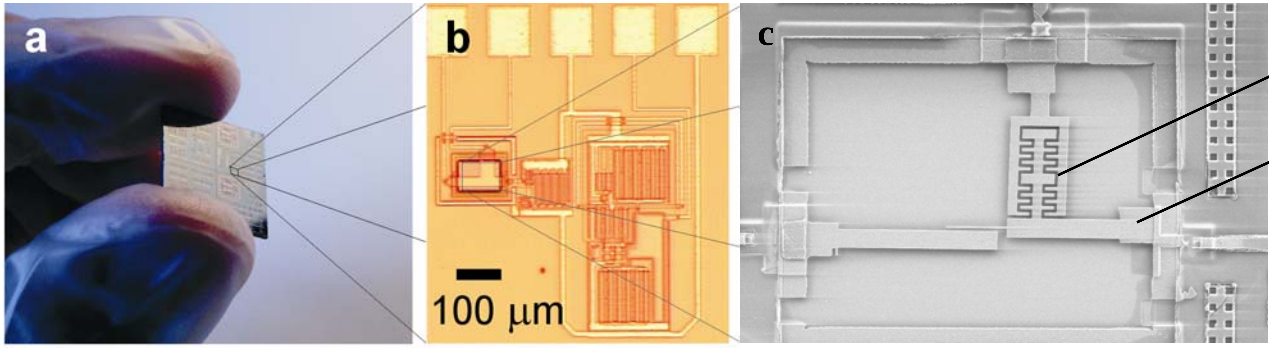
small cantilever

less moving mass
(less kinetic energy)

higher influence of added mass
on cantilever vibration

w(μm)	h(μm)	l(μm)	f_{res} (Hz)	$\Delta m/\Delta f$ (g/Hz)
2.0	40.0	242.0	48.0kHz	1.9×10^{-12}
0.5	2.0	22.0	1.4MHz	7.4×10^{-17}
0.1	0.5	2.8	17.8MHz	3.7×10^{-20}

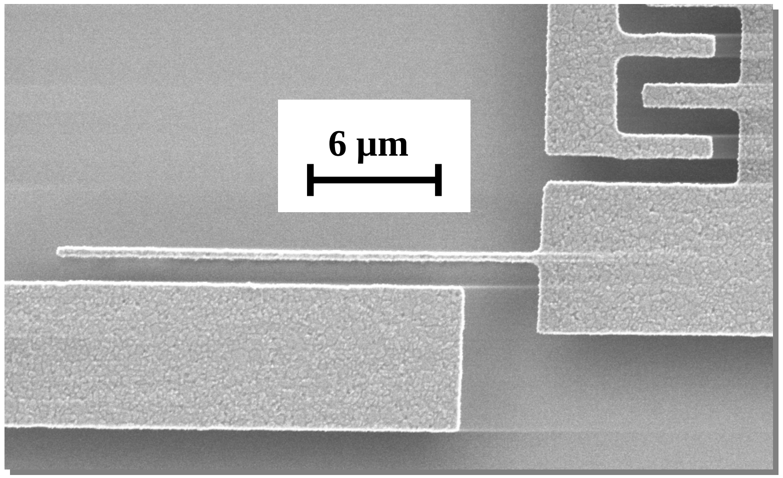
Resonator Device in CMOS



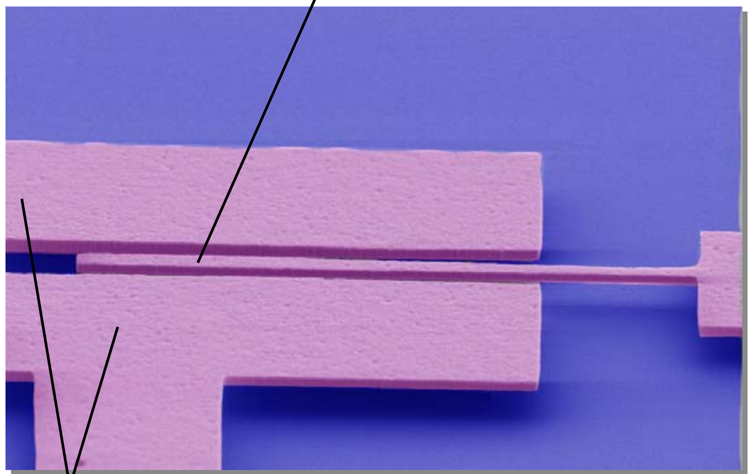
EBL defined, <5kV

DWL defined

Poly-Si cantilever; 400 nm wide, 600 nm thick and 25 mm long, made by low energy EBL combined with DWL



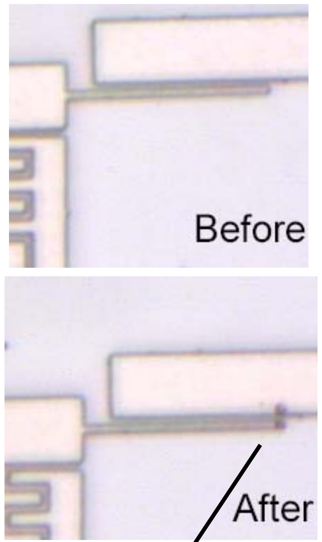
Top view SEM image of a 400 nm wide poly-Si cantilever



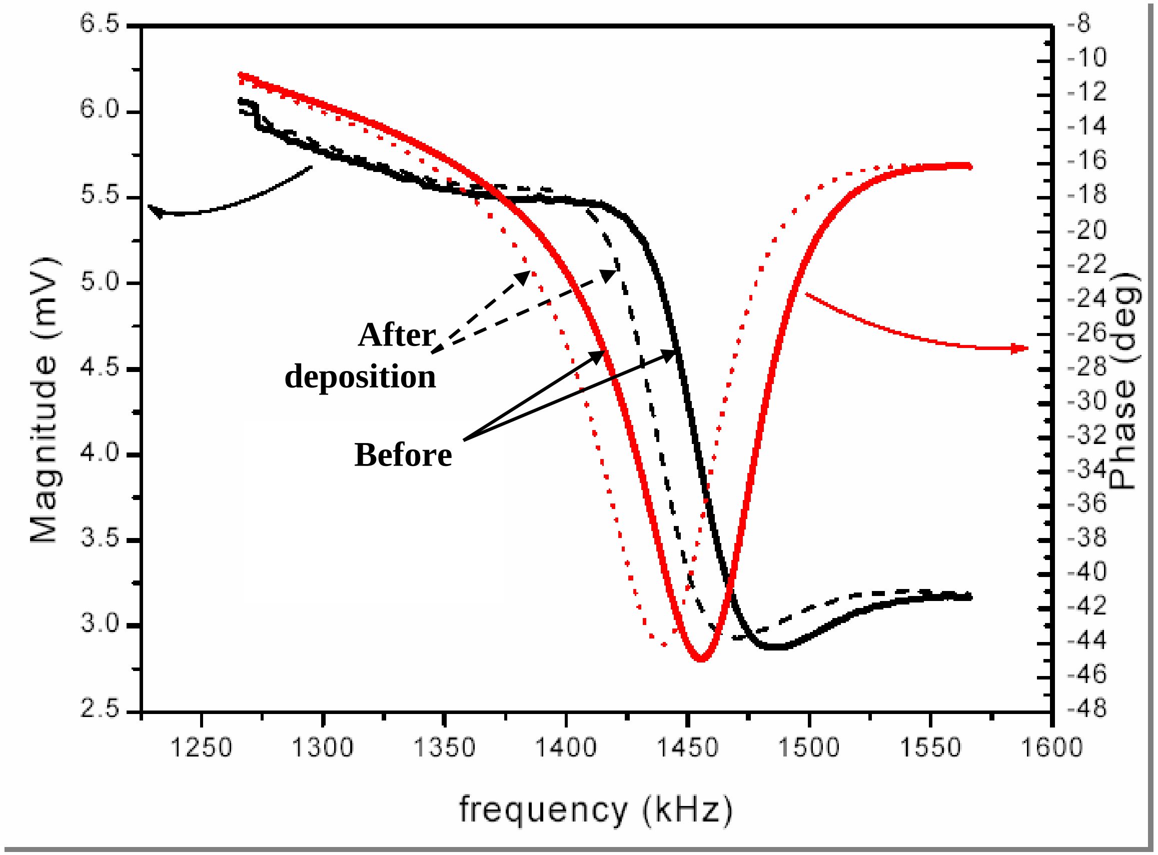
Poly-Si electrodes used for electrostatic excitation and for capacitive read-out

Esko Forsén

Mass Measurement in Air



Glycerine drop
d≈500 nm



Dimensions:

w ≈ 420 nm

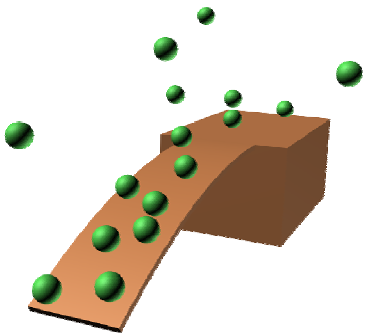
t ≈ 600 nm

l ≈ 20 mm

Mass Glycerine drop **~ 40 fg** $\Delta f = 14.8\, kHz$ $\frac{\partial m}{\partial f} \approx 3 \cdot 10^{-18}\, g / Hz$

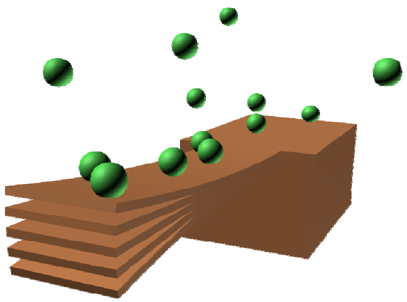
Gabriel Abadal

Summary of Modes



static

- surface stress
- bi-morph effect
- conversion of chemical into mechanical energy
- dry and liquid

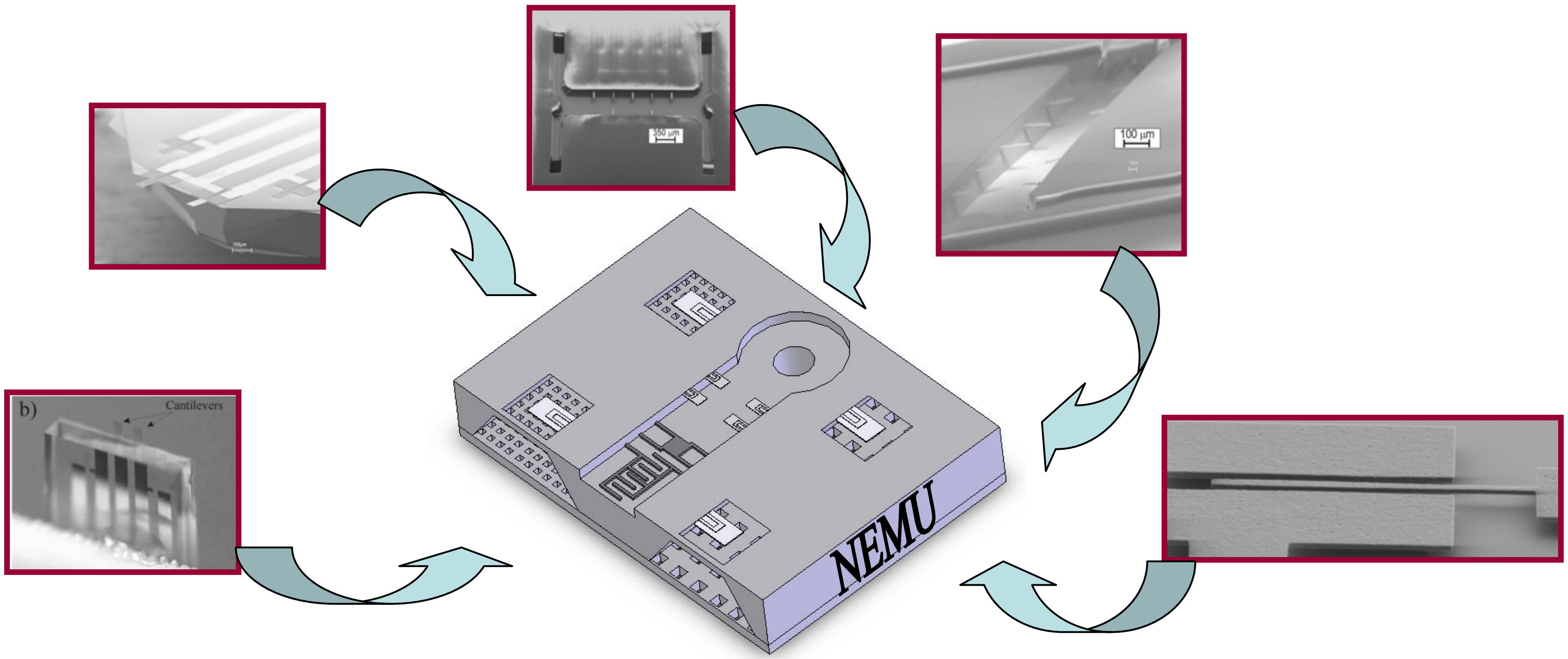


dynamic

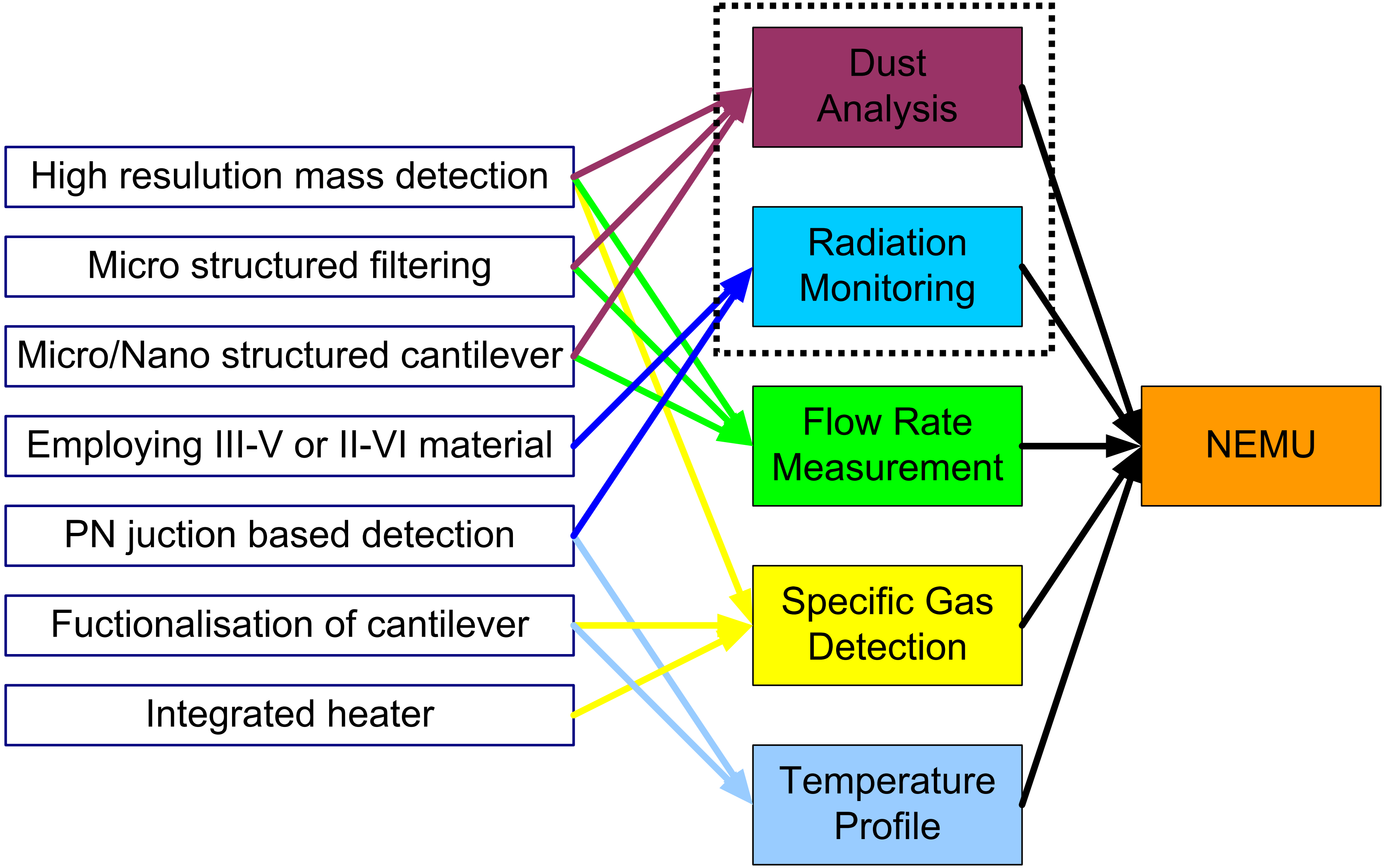
- mass
- resonance frequency shift
- dry (difficult in liquid)

NEMU
Nano Environment Monitoring Unit

- Highly integrated cantilever based sensor
- Combining advantages form cantilevers operating in both dynamic and static mode



Design & Development Map

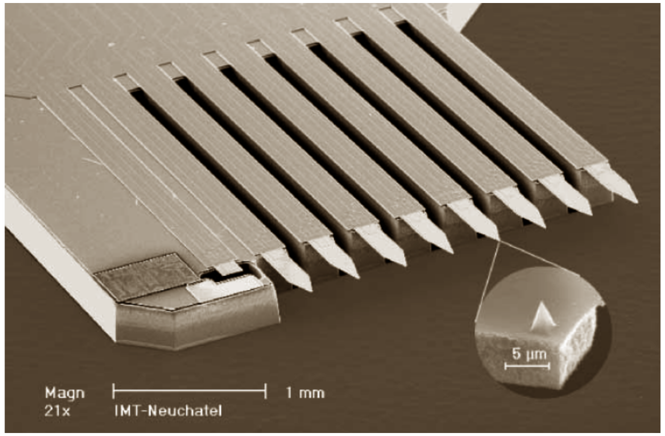


Main Issues

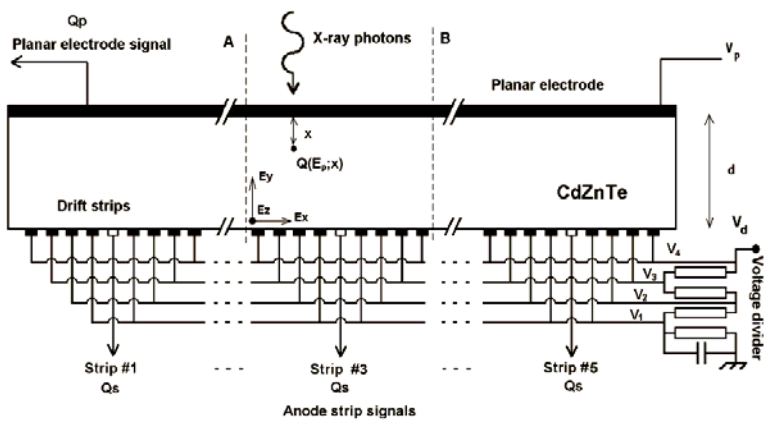
- Integration complexity
- Optimal actuation of resonator
  - Integrated or global
  - Electrostatic, piezoelectric, thermal, magnetic
- Limit of detection by integrated read-out
  - Optical, capacitive, piezoresistive
- Functionalisation of cantilever
- Stresses during launch/re-entry

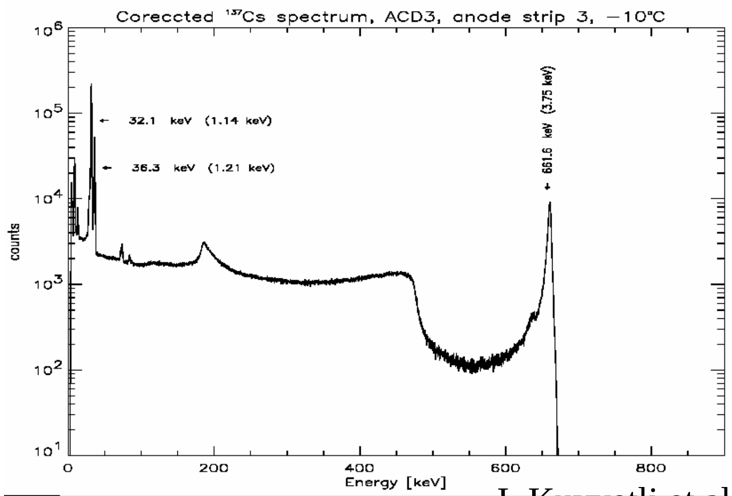
Comparable Systems

- AFM for Phoenix 2007 Mars Scout Lander
- QCM for Pathfinder
  - 20g without electronics
  - ~10^{-12}g/Hz resolution
    - ~10^{-18}g/Hz for cantilevers
- Pixelated CdZnTe drift detector
  - Hard X-ray and gamma ray
  - Excellent spectral performance possible
  - Needs optimisation



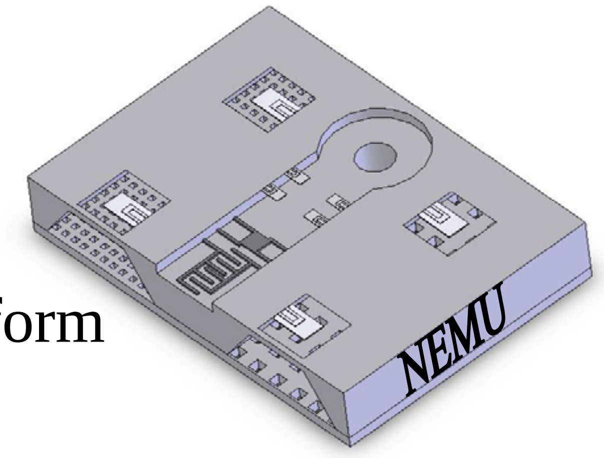
T. Akiyama et al.





I. Kuvvetli et al.

Outlook & Status



- Status
  - Initiation of project
    - Analysis of dust particles
    - Radiation monitoring
  - DTUsat2 (Cubesat) as initial test platform
    - First operating micro-cantilever in space
- Alternative applications
  - Local information of outgassing amounts
  - Radiation distribution in space craft
  - Leak detection in e.g. propulsion systems
  - Flow measurement in life support equipment
  - Unit suitable for both robotic and human missions
  - Terrestrial personal security/warning system or general pollution