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MEMS based sensors for indoor environment applications

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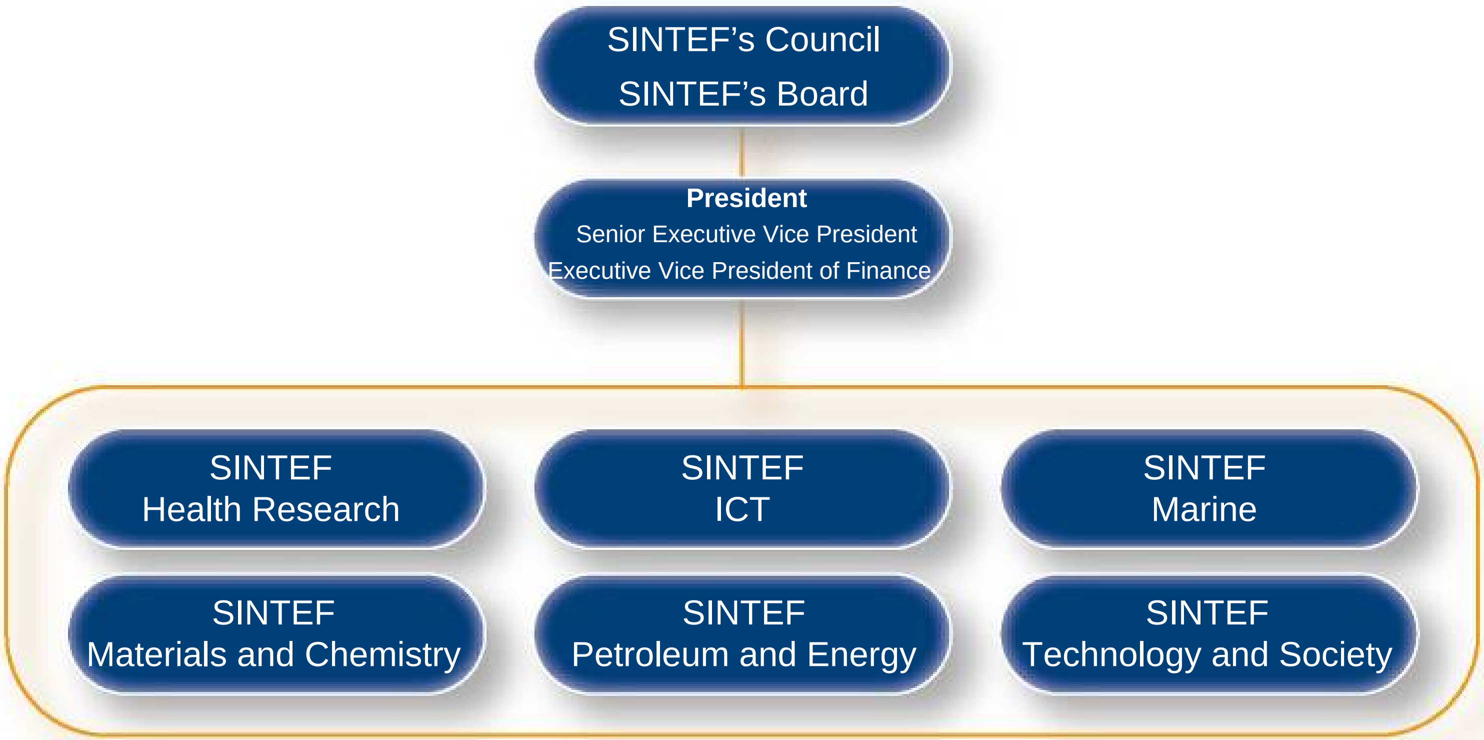
The SINTEF Group



MiNaLab (Micro Nano Lab)

- Clean room area:
  SINTEF: 800 m²
  University of Oslo: 600 m²
- Micro environments, class 10
- A full silicon processing line for MEMS and radiation detectors
- Capacity of 10.000 6” wafers/year
- 35 employees at SINTEF
- Located at the campus of University of Oslo
- 240 MNOK invested in scientific equipment and laboratory infrastructure
- Funded by Norwegian Research Council and SINTEF

MiNaLab offer

- One of two silicon processing lines in Norway. The only *independent one*.
- Offers the complete range from *design, process and device development through flexible prototyping and production*.

- **Production:**
  - Contract production of MEMS using processes not commercial available in industrial foundries.
  - Contract and foundry production of radiation detectors.
- **MEMS design center:**
  - SensoNor process = MULTIMEMS
  - Other available foundry processes
  - In-house MEMS processes

Key parameters for IAQ control

- Temperature
- CO_2
- Humidity
- Other gases (e.g. CO)

There is a strong demand for (networks of) low cost multi sensors

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Infrared (IR) gas sensing

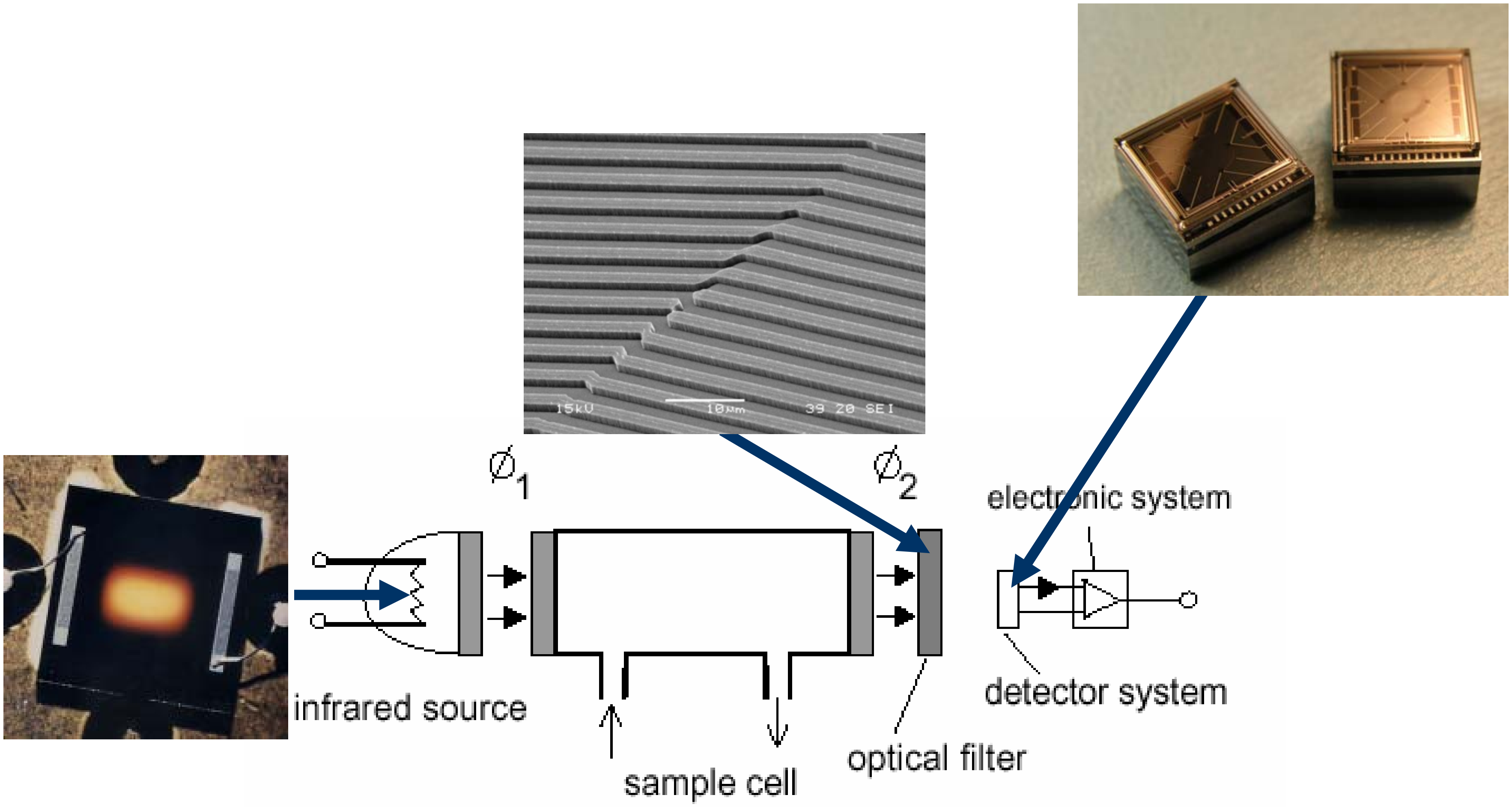
Advantages:

- Selective
- Sensitive
- Non contact
- Reliable

Disadvantages:

- Inherently expensive (at least two components)
- Large size
- Requires drift compensation
- Complex packaging

MEMS devices for infrared gas sensing



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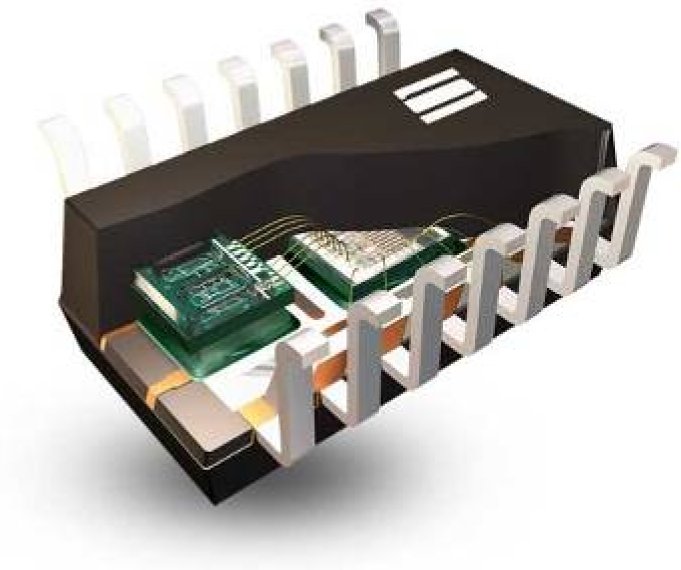
Micro ElectroMechanical Systems (MEMS)

Miniaturized systems that carry out several operations.
Typically: sensing, singnal conditioning and actuation

- **Micro sensor and/or actuator**
- **ASIC**
- **Packaging**



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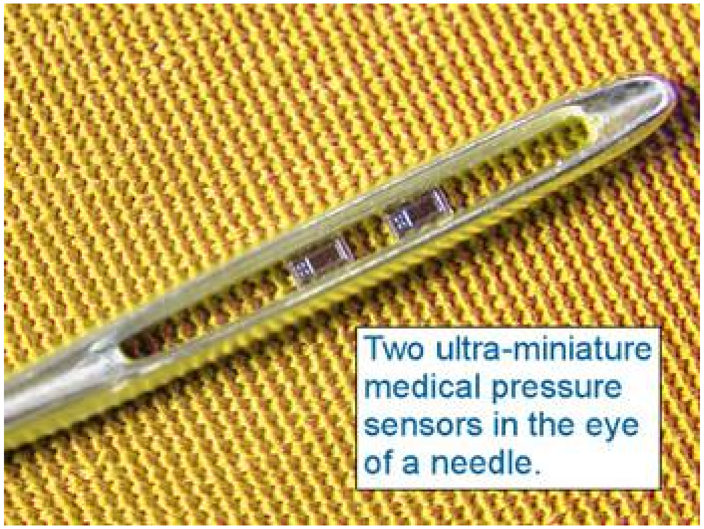
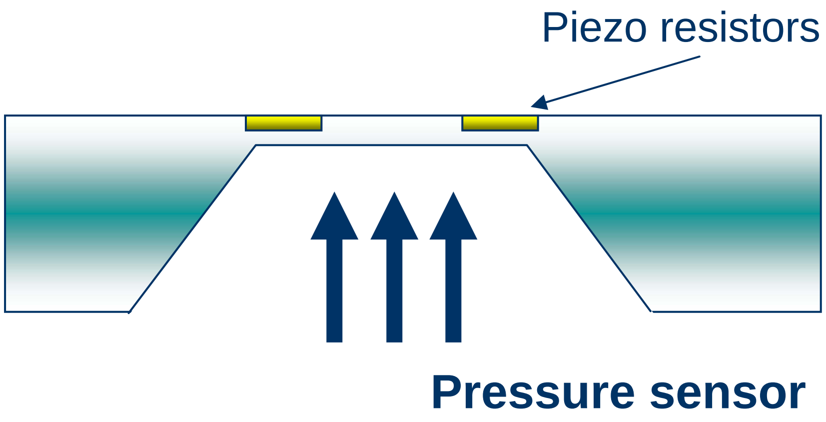
Microsystem technology

- Utilizes the production technology developed for microelectronics to make sensors **(MEMS)**
  - Miniaturization
  - High volume, low cost production
  - Integration with electronics

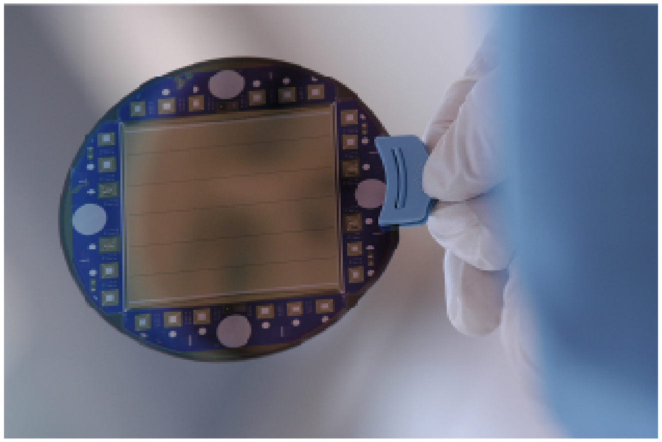


- Special processes
  - Micromachining
  - Functional thin films
  - Wafer stacking



Why silicon technology

- Batch processing => low cost, high volume
- Well established production technology
- Advanced infrastructure, materials and design tools available
- Wide range of sensor principles available
- Silicon has attractive mechanical properties
- Integration is possible



IR sources

- Thermal sources
  - Conventional “light bulbs”
  - MEMS based IR sources
- IR LEDs
- IR LASERS

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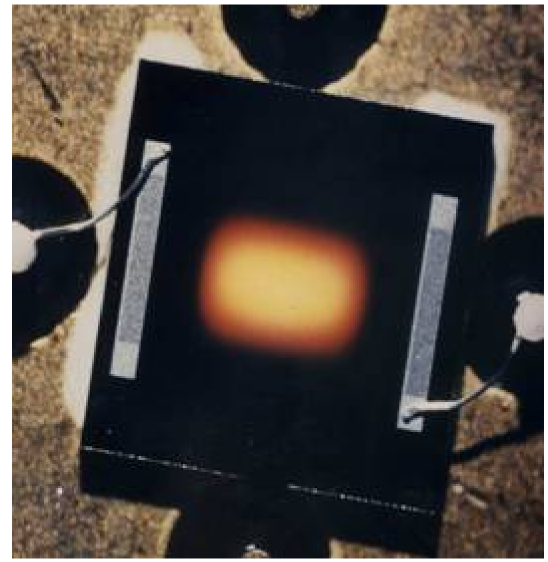
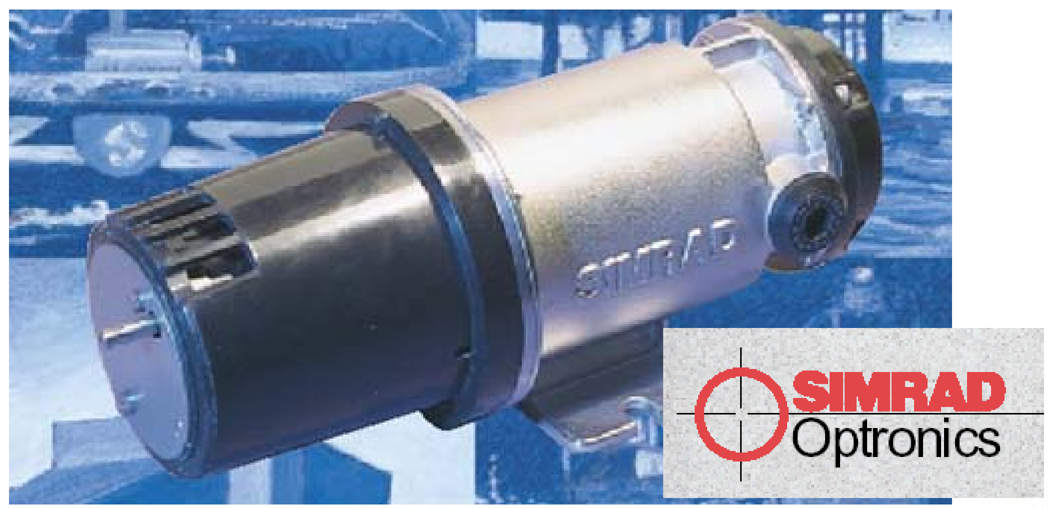
The SINTEF infrared emitter

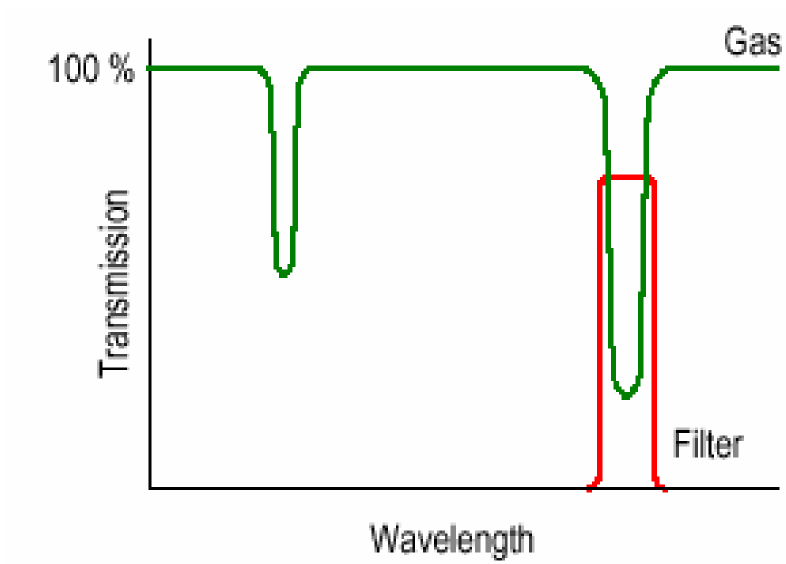
- Produced by silicon micromachining
- Grey body spectrum
- Electronically controlled modulation
- Modulation depth: 20 % @ 50 Hz
- Power consumption: ~ 1 Watt
- Application example:
  SIMRAD Optronics Gas Detector
  for methane (CH4)
  More than 15 years of
  continuous operation
  in the North Sea

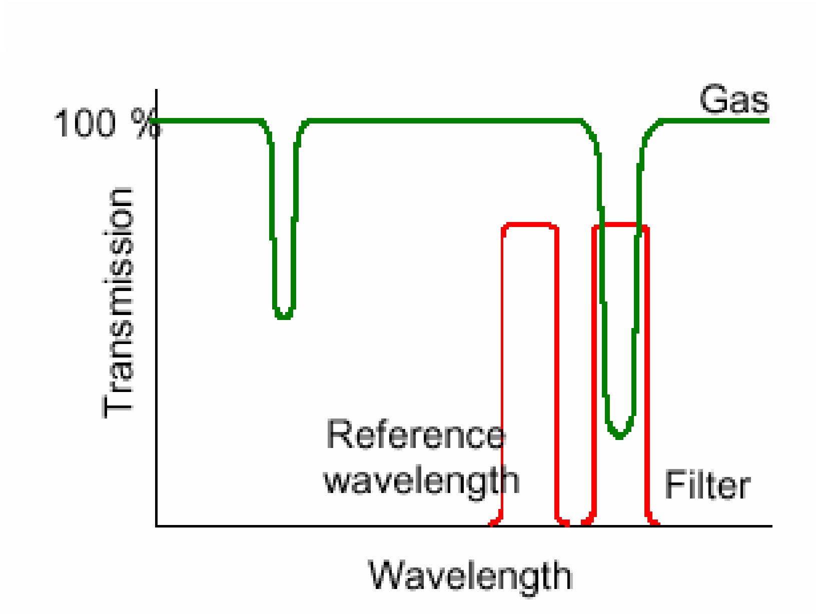




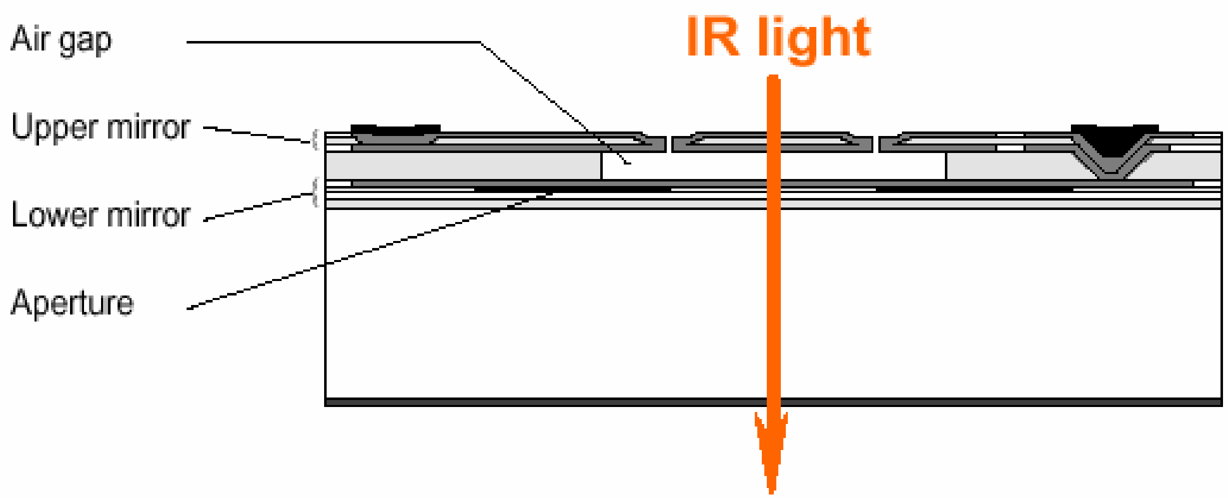
Filters

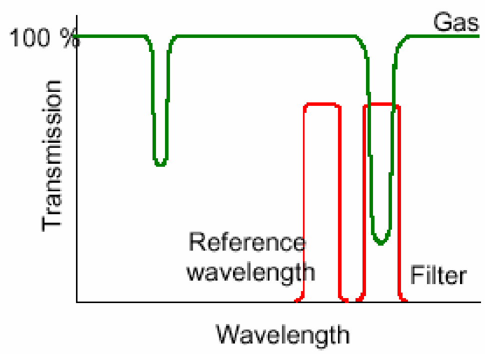
- Single gas selectivity
- Compensation
- Multi gas detection (CO, humidity)





The Carbocap® technology from VAISALA





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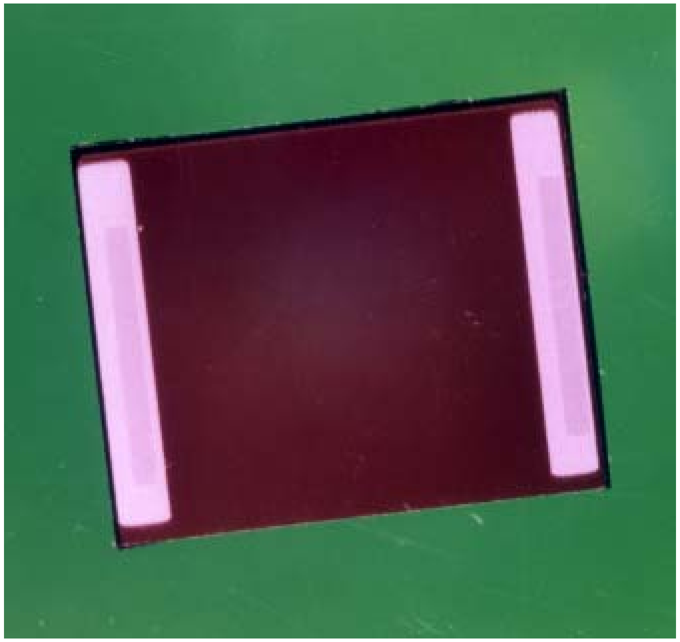
A CO and methane sensor based on a thermally tuned Fabry-Perot filter

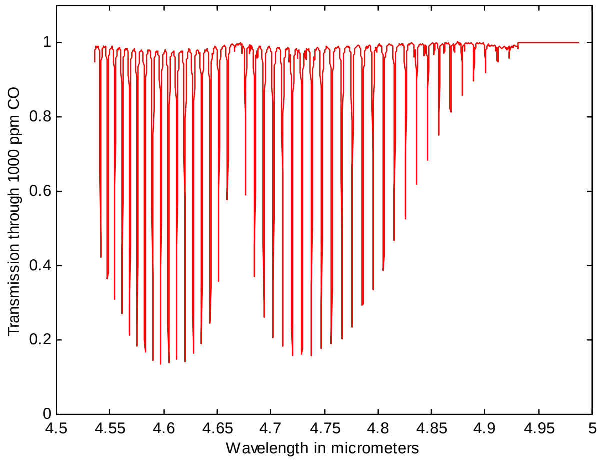


- Micromachined in silicon
- Based on the thermo-opto effect

$\Delta T \sim 25^{o}$ C

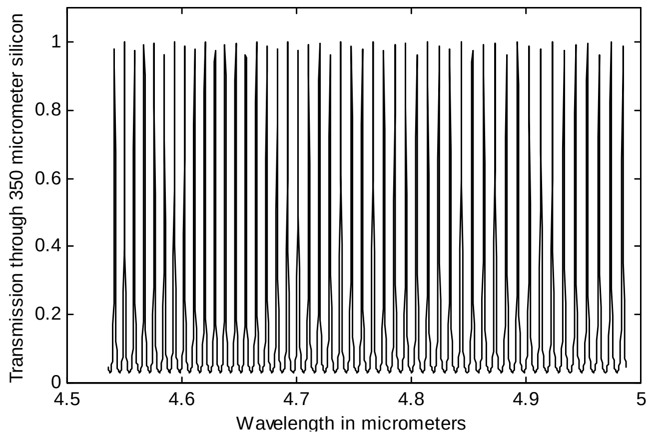
- Designed to synthesize a characteristic gas spectrum
- Electrically modulated 10 nm
- Wavelengths from 1.2 µm ->
- Modulation frequency: 1 Hz
- Simple design, low cost

Rogne, Bernstein, Avset, Ferber, and Johansen
MOEMS '99, Heidelberg

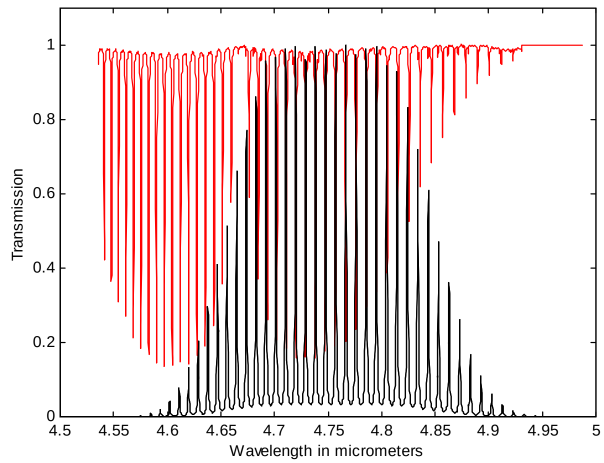


CO absorption pattern

+



Absorption pattern synthesized by multi-line filter



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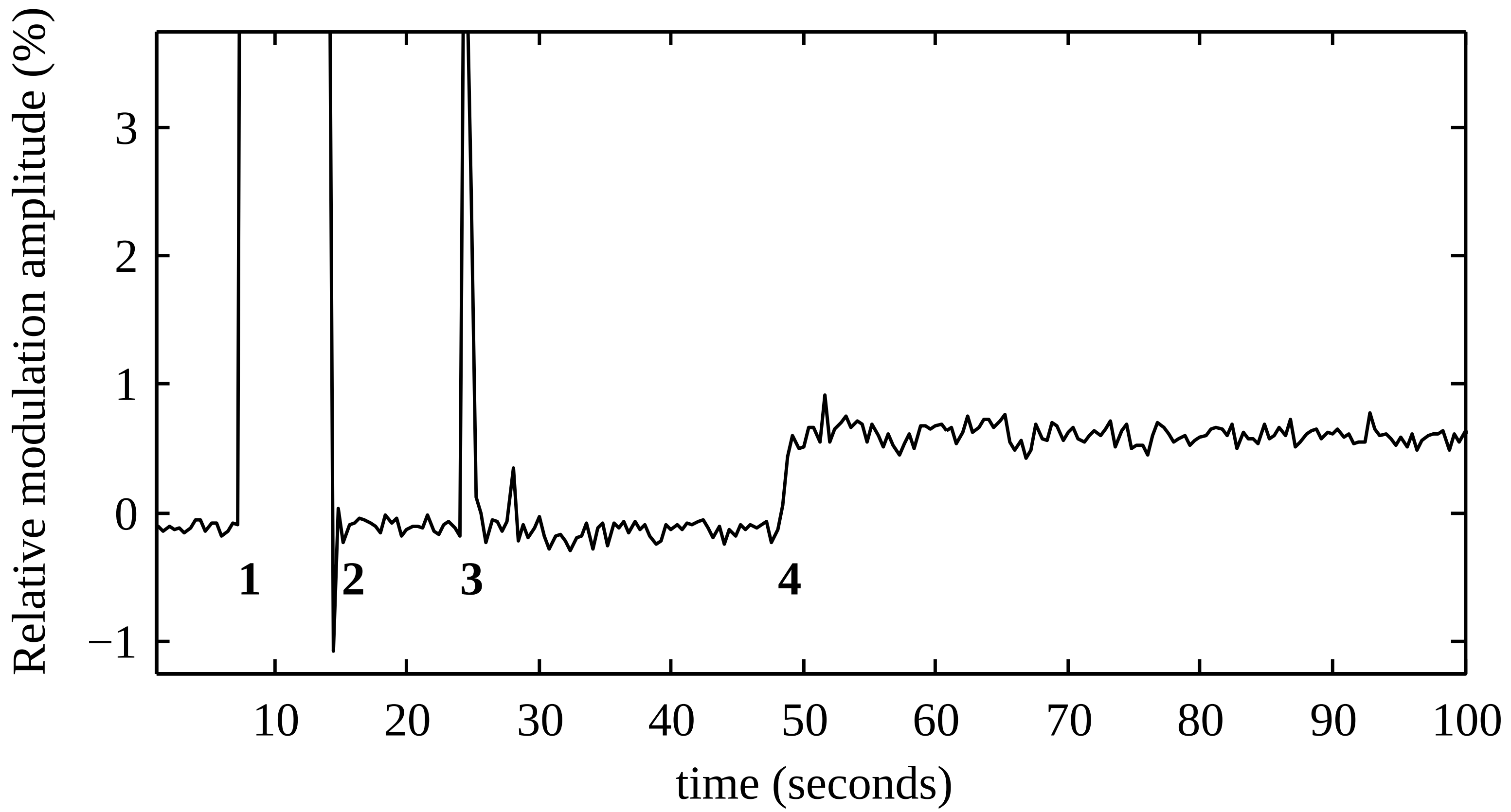
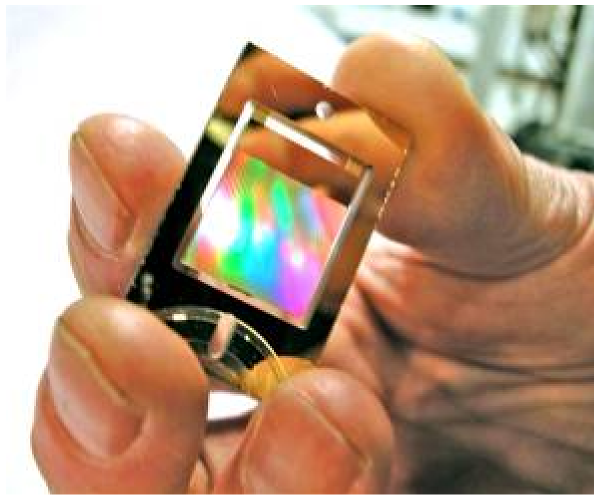
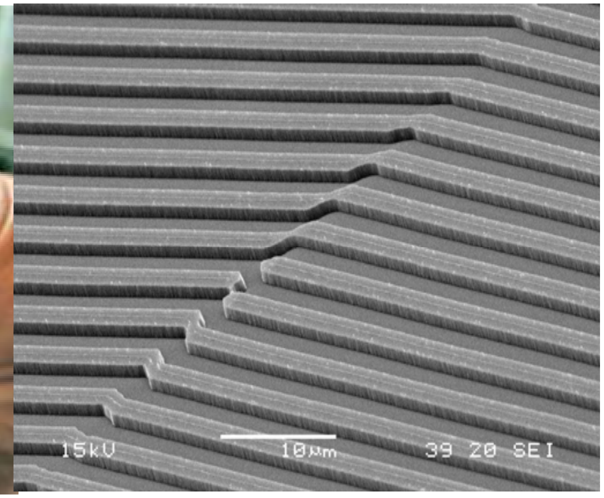
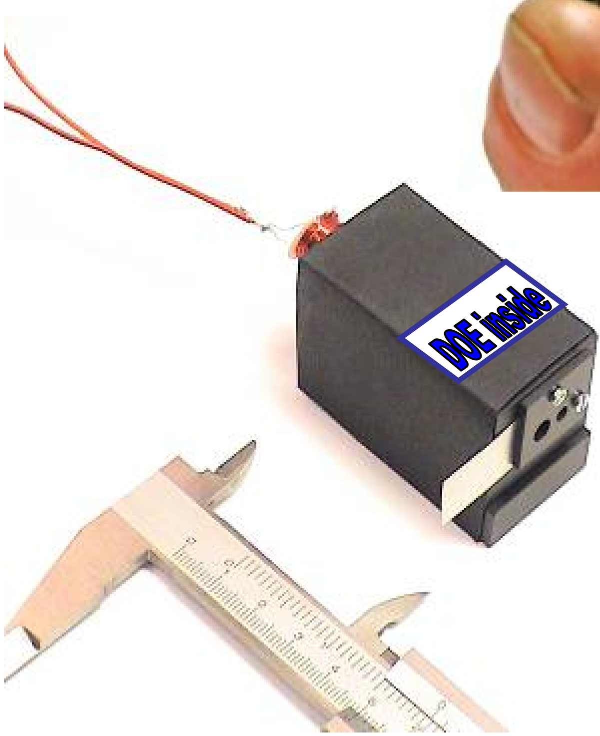
CO measurments with the slab sensor

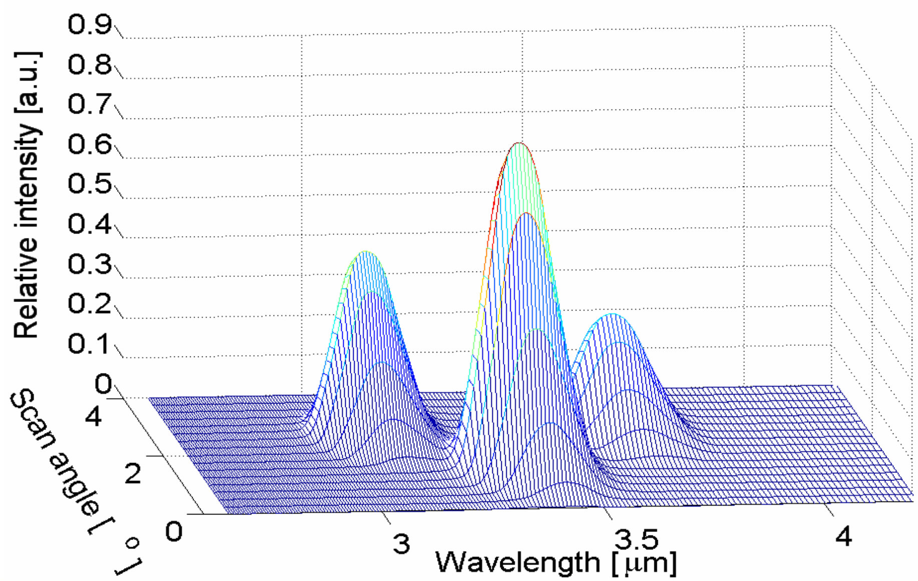


Diffractive optics for gas sensors



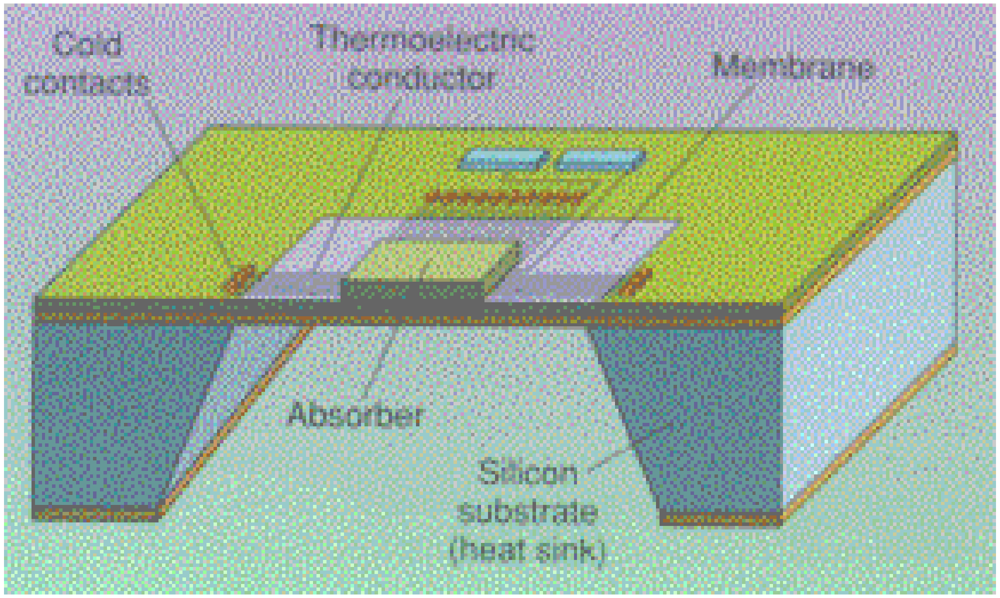






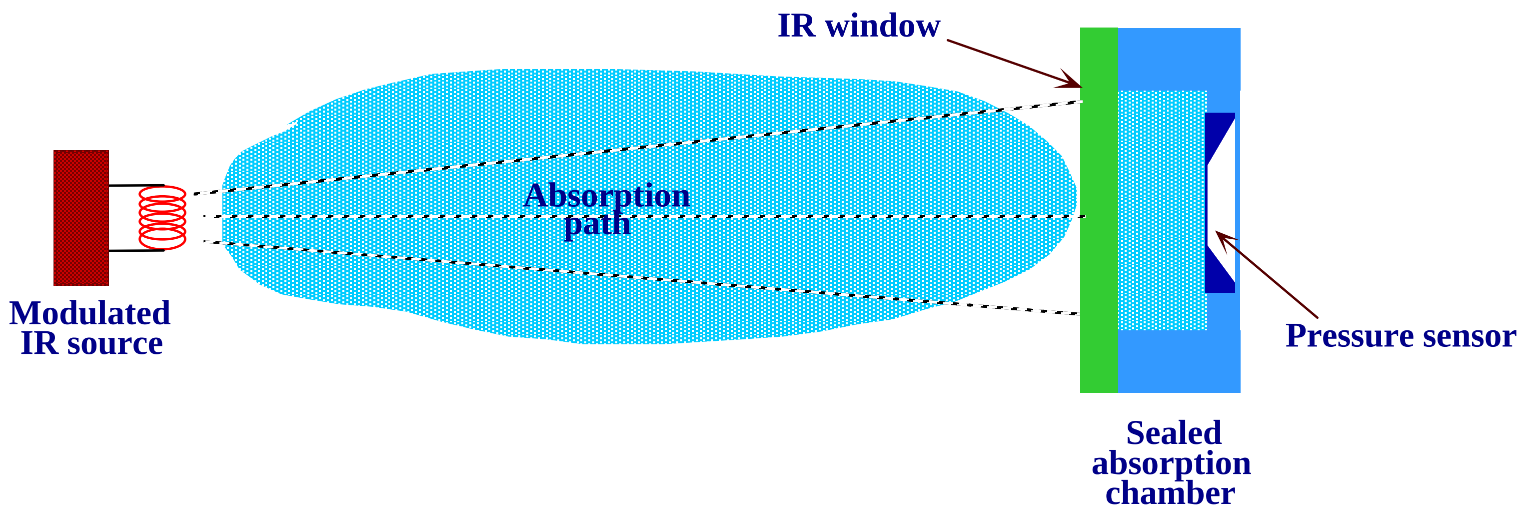
MEMS based IR detectors

Thermopile detector

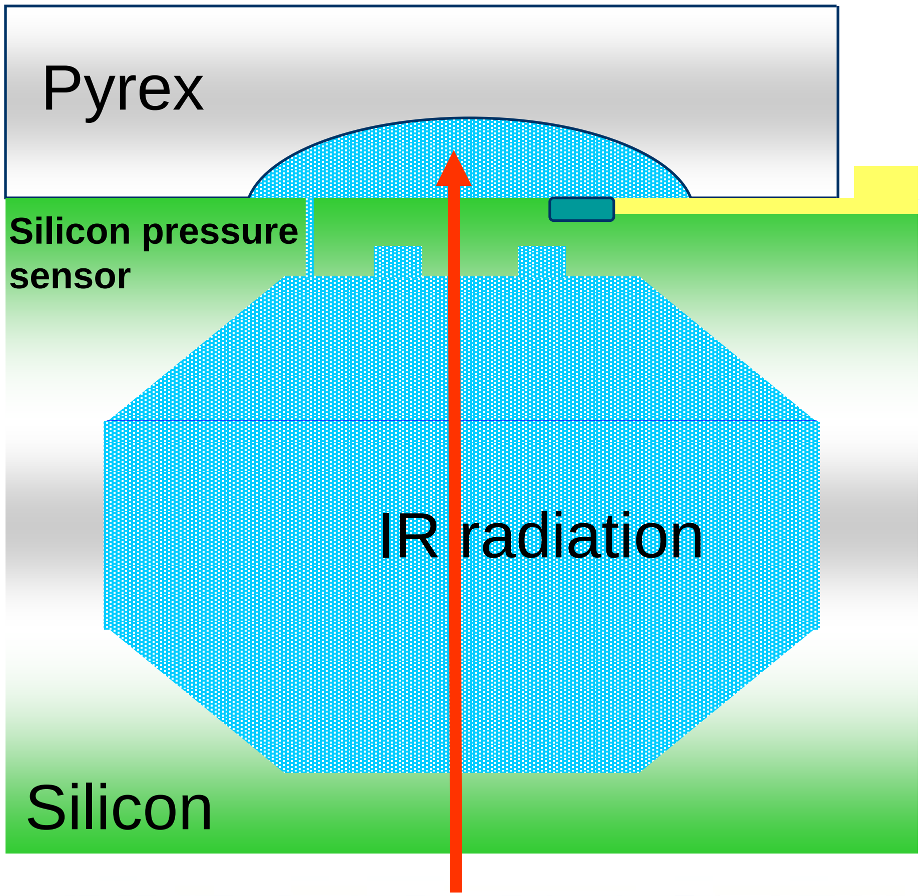


Wolfgang Schmidt and Jörg Schieferdecker

Filter and detector in one chip:
The SINTEF photoacoustic gas sensor

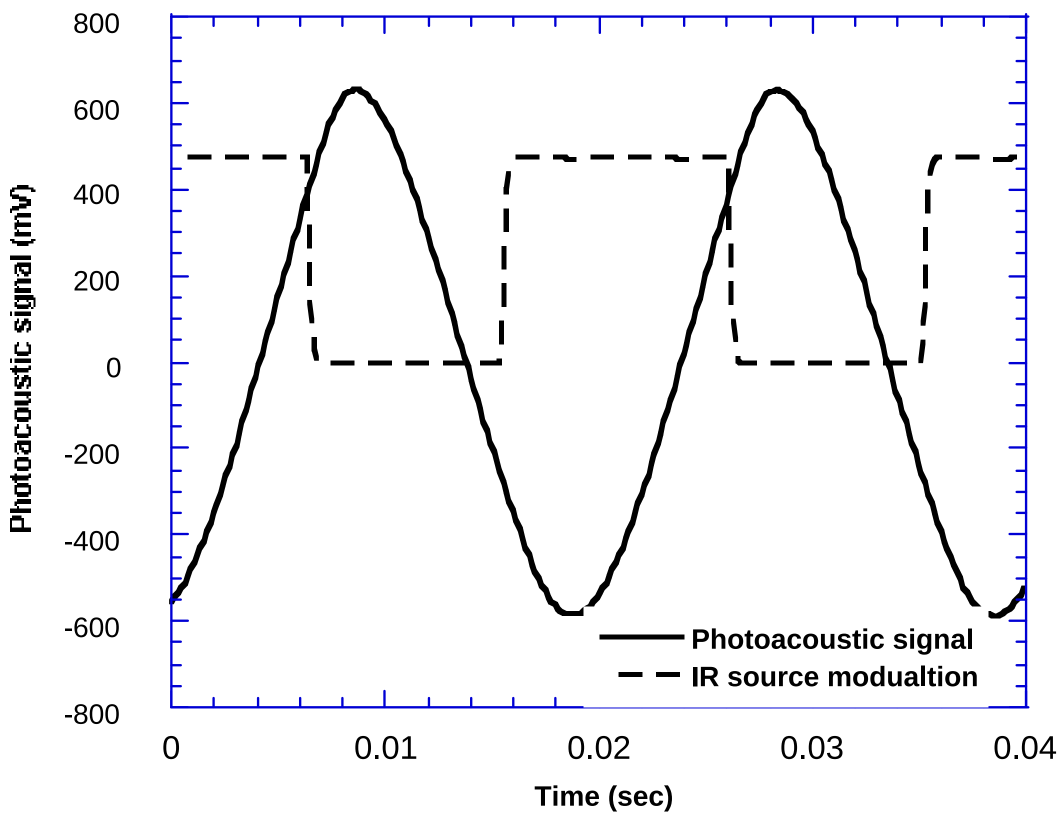


The photoacoustic detector chip



- Wafer level gas filling
- High precision piezoresisive pressure sensor
- Transferred to the SensoNor MPW foundry process

The photoacoustic signal



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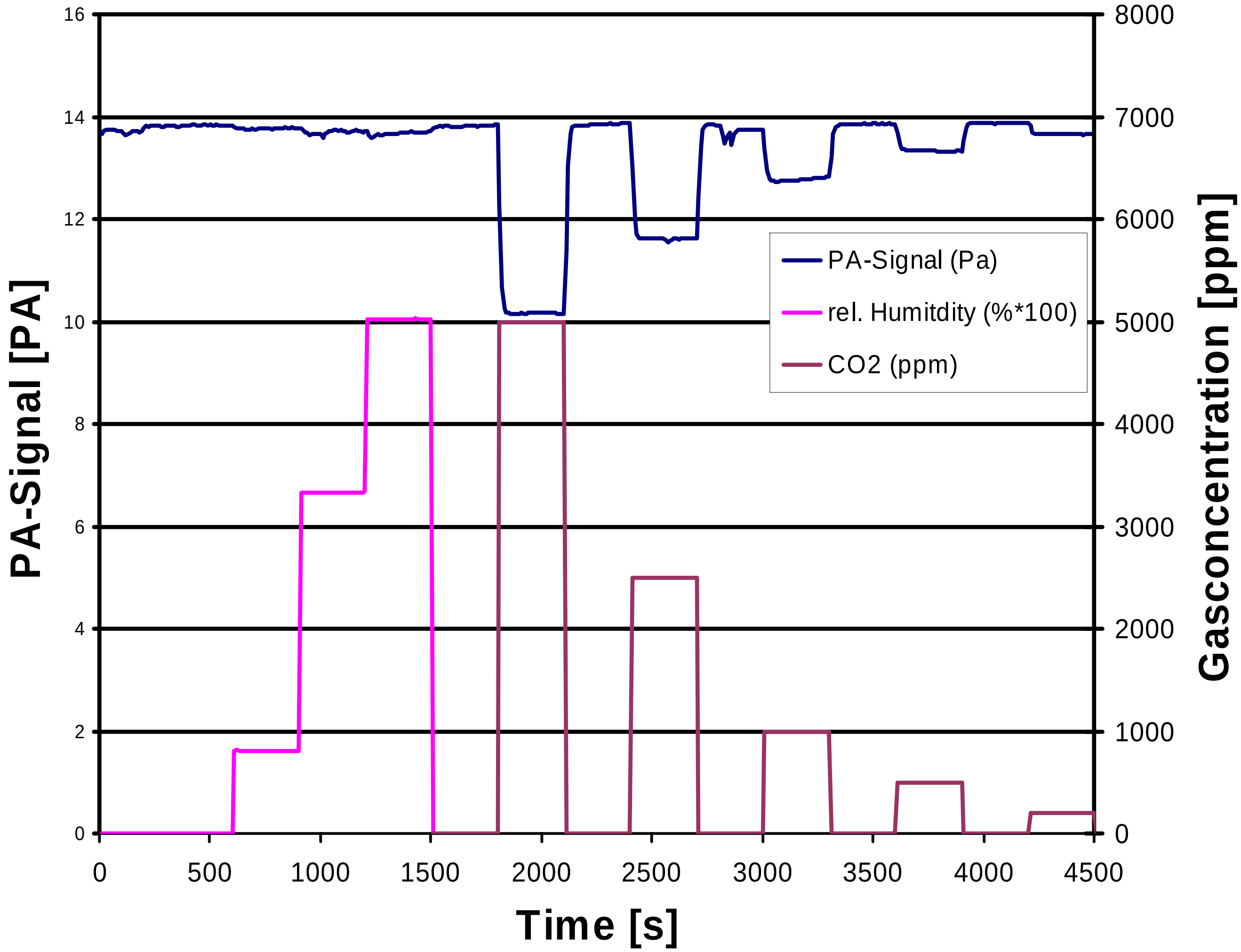
CO_2 Measurement with the PA sensor:



200-100 ppm resolution

Characteristics

- High selectivity without additional filters
- High sensitivity => small size
- No pumps and valves
- Easily implemented in MEMS technology => low cost

- High volume production an packaging technology required
- Long term drift compensation has to be implemented

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MASCOT: Micro-Acoustic Sensors for CO_2 Tracking

Per Gerhard Gløersen, SensoNor AS
Bertil Hök, Hök Instrument AB
Niels Peter Østbø, SINTEF

MASCOT
Micro Acoustic Sensor System for CO_2 Tracking

The MASCOT project was co-financed by the IST programme of the European Commission under grant number IST-2001-32411

Electro-acoustic IAQ sensor

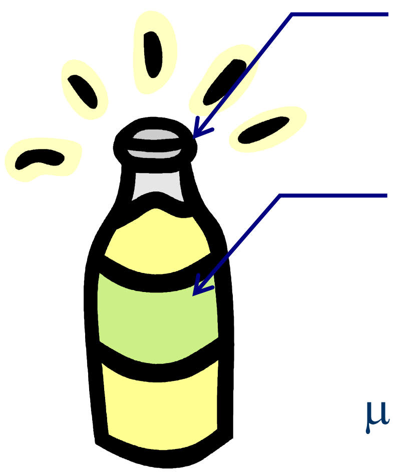
Device modelling basics

Relationship between velocity of sound c and molecular mass M of a gas:

$$c = \sqrt{\frac{RT\gamma}{M}}$$

R: universal gas constant (=8.314 J/mol K),
T: absolute temperature (K)
γ: Ratio of specific heat at constant pressure and volume

Resonant frequency and Q of a Helmholtz resonator:



Neck effective length l and area A (radius a)

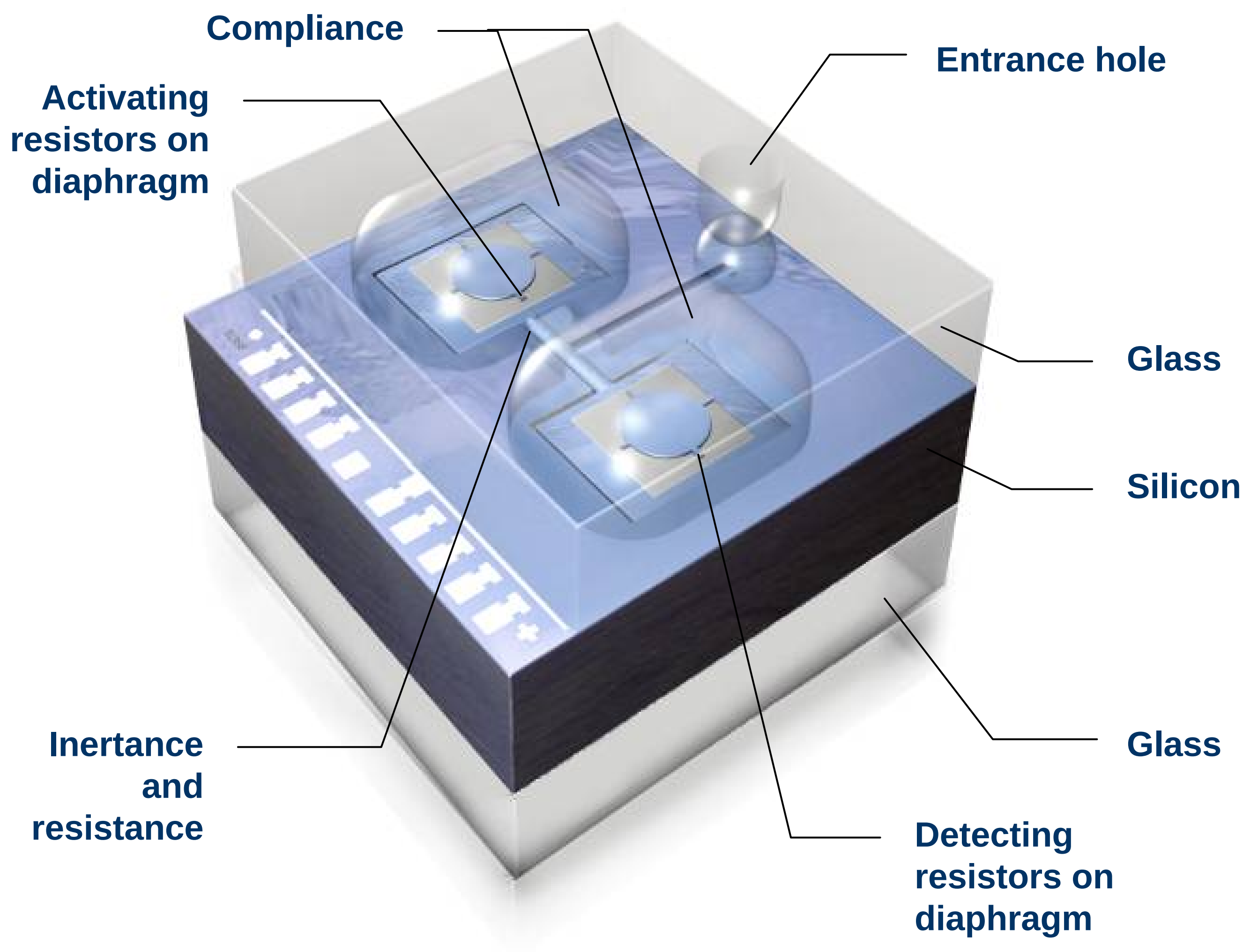
Compliant gas volume V

$$f_r = \frac{c}{2\pi}\sqrt{\frac{A}{\ell \cdot V}}$$

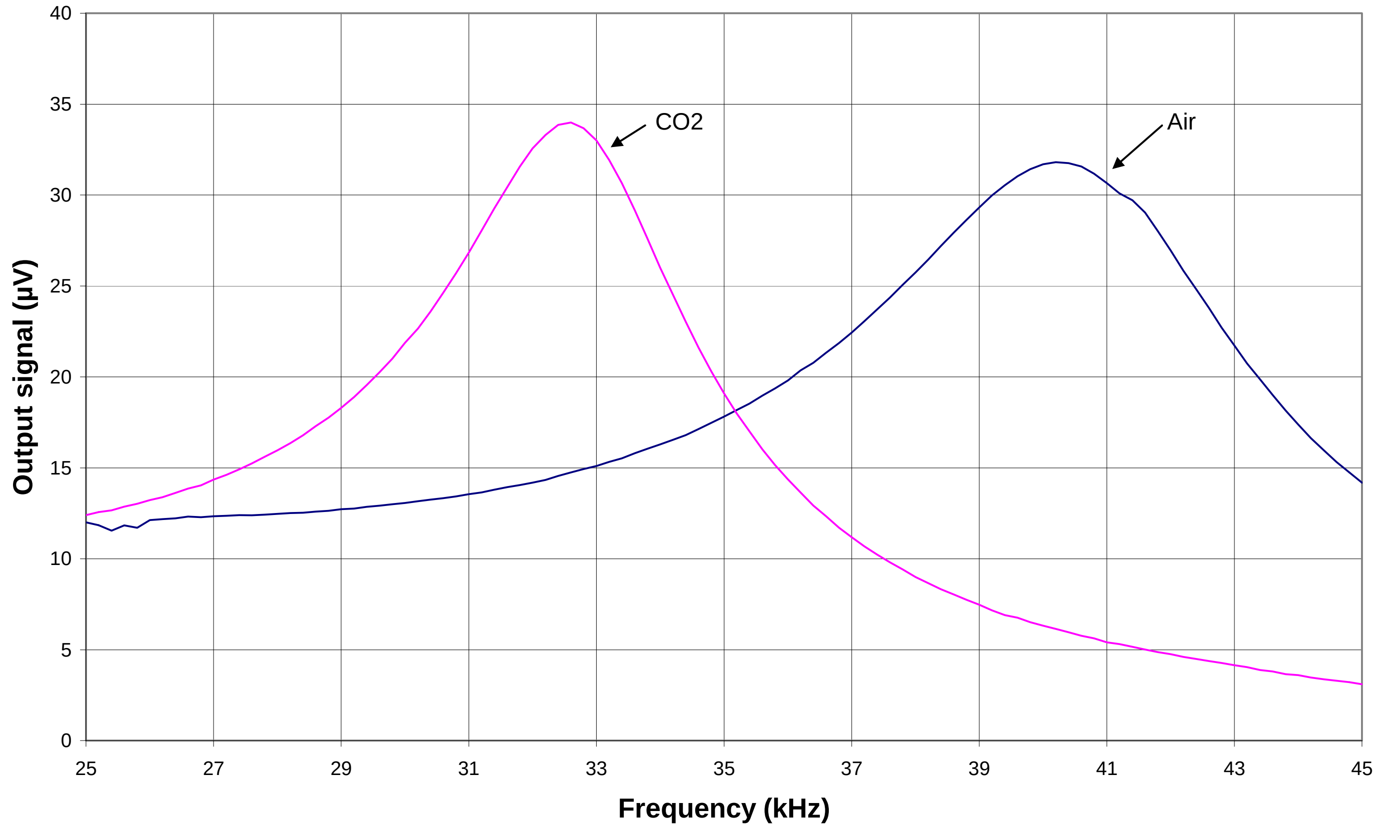
$$Q \approx a \cdot \sqrt{\frac{\omega_r}{2\mu}}$$

μ: kinematic viscosity of gas

Schematic drawing of sensor chip



Sensor output signal in air and CO_2



The resonance frequency shifts from 40 to 32 kHz and the Q factor increases from 6.5 to 8.1

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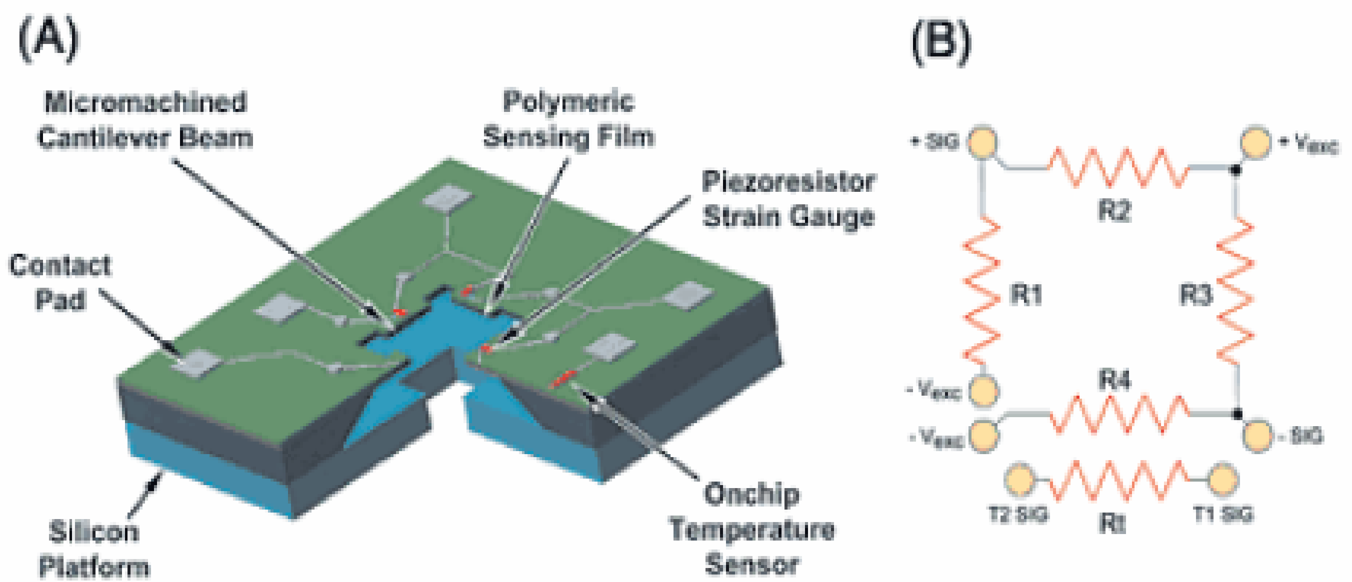
Sensor characteristics

	f_r	Q
Typical value	*40250 Hz*	*6.60*
CO_2	*-11 Hz/1000ppm*	*+0.009/1000ppm*
RH	*+4 Hz/%RH*	*-0.001/%RH*
Temp	*63 Hz/°C*	*-0.015/°C*
Pressure	*0*	*+0.04/kPa*
Resolution	*±2 Hz (±200 ppm CO_2 or ±0.5% RH)*	*±0.01*

MEMS based humidity sensors



Die Size: 2 mm x 2 mm

Figure 3. The HMX2000, a silicon-based RH sensor, contains a full Wheatstone bridge circuit and a temperature sensor on a single chip (A). The circuitry is shown for the devices on the sensor chip (B).

HYGROMETRIX

Some aspects of multi sensors

- The challenge is often NOT to be sensitive to humidity and temperature
- Temperature sensors are easily implemented as an integral part of standard electronics.
- Multi sensors are often based on MCM integration.
- MEMS devices is potential easy to integrate since the are small and often based on the same principles (piezoresistive, capacitive and optical)
- MEMS also opens for a higher degree monolithic integration
  - Temperature sensors as part of the gas sensor chip

Conclusion

- IR technology offers highly sensitive, selective and reliable gas sensors.
- MEMS based IR sources, IR detectors, tuneable optical filters, and complete gas and humidity sensors are available.
- IR gas sensors are, however, still expensive due to large size, expensive components, packaging, and drift compensation. Higher level of integration is required.
- A DOE based CO_2 under industrialization by Optosene AS
- A MEMS based photo-acoustic gas sensor for CO_2 is demonstrated offering high selectivity, sensitivity, and is compatible with MEMS technology.
- A new class of electro-acoustic MEMS-implemented CO_2 sensors has been demonstrated:
  - Simple and uncritical geometry
  - Strong potential for mass-production at low cost
- A CO sensor based on a thermally tuned F-P filter is demonstrated. The detection limit for CO was 20 ppm•m, and 50 ppm•m for methane.
- MEMS based sensors are by their small size and fabrication and packaging technology potentially suitable for multi-sensor integration