Advanced MEMS and Microsystems

Dr. Danick Briand, Prof. Guillermo Villanueva

Course content and schedule

Dates	Topics	Lecturers
18.02	Introduction Transducers review: pre-recorded lectures	D. Briand / G. Villanueva
25.02	Sensors part I Exercices	D. Briand
04.03	Sensors part II Industrial seminar #1	D. Briand
11.03	Students presentations	D. Briand / G. Villanueva
18.03	Actuators and Optical MEMS Industrial seminar #2	D. Briand
25.03	Acoustic and Ultrasonic MEMS Industrial seminar #3	G. Villanueva
01.04	RF-MEMS	G. Villanueva
08.04	NEMS	G. Villanueva
15.04	Interactive session	D. Briand / G. Villanueva
29.04	Thermal and gas sensors Industrial seminar #4	D. Briand
06.05	Packaging	D. Briand
13.05	Packaging Industrial seminar #5	D. Briand
20.05	PowerMEMS Industrial seminar #6	D. Briand
27.05	Quiz at home NO CLASS	All

Announcements

TODAY 29 April 2025

- Lecture on Thermal Microsystems and Gas Sensors
- Seminar 4 – APIX at 12h15

NEXT WEEK 06 May 2025

- Lecture on MEMS Packaging
- Answers to Seminar APIX to handle in

WEEK 13 May 2025

- Lecture on MEMS Packaging
- Seminar 5 – CSEM at 10h15

INSTRUCTIONS ORAL EXAM

- Available on moodle with the schedule

LESSON 7 – Thermal Microsystems and Gas Sensors

Dr. Danick Briand

Maître d'Enseignement et de Recherche (MER)

Team leader MEMS & Printed Microsystems

EPFL-STI-LMTS

Lecture content

- Heat transfer, micro-hotplates, IR-emitters
- Thermal flow sensors and accelerometers
- Fundamentals on chemical sensors
- Miniaturized gas sensors
  - Thermal
  - Chemoresistive
  - Field-effect
  - Optical
  - Chemomechanical
- Some potential exam questions

Heat transfer and dissipation

- Thermal energy $\Rightarrow$ Q (J)
- Thermal energy / volume $\Rightarrow$ Q_v (J/m^3)
- Heat flow $\Rightarrow$ $\dot{Q} = I_Q$ (W)
- Heat flux $\Rightarrow$ J_Q (W/m^2)

Heat transfer

Heat transfer and dissipation: types of heat flow

- Flow proportional to a temperature gradient
  - Heat conduction in materials

$$J_Q = -\kappa \nabla T$$

K: thermal conductivity

- Convective heat transfer
  - A subject coupling heat transfer to fluid mechanics

$$J_Q = h_c (T_2 - T_1)$$

h: convection coefficient fct. of flow nature of fluid, area

- Radiative heat transfer
  - Between two bodies (at $T_1$and T_2)
  - Stefan-Boltzmann Law
  - Can NEVER turn off

$$J_Q = \sigma_{SB} F_{12} (T_2^4 - T_1^4)$$

$$Q = \varepsilon\, \sigma\, T^4 A$$

ε : emissivity of the material

F_{12}: view factor is the proportion of the radiation which leaves surface 1 that strikes surface 2

Joule heating

Heat transfer and dissipation: Joule heating

Joule heating definition

Joule heating is the process by which the passage of an electric current through a conductor releases heat.

- The extra energy is lost to Joule heating in the resistor

$$P_R = IV_R = I^2 R = \frac{V_R^2}{R}$$

- Globally, the power entering a resistor is given by the *IV* product.

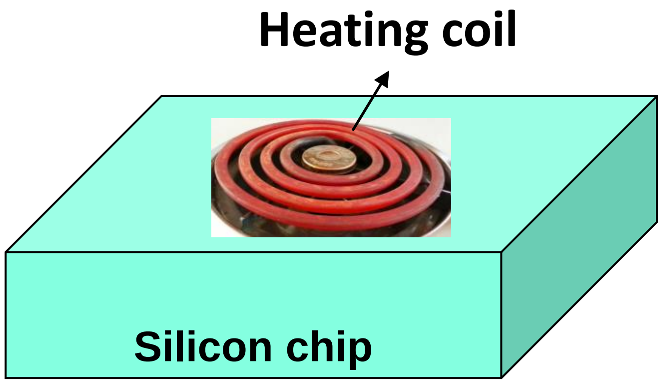
$$P_R = J_e E = \sigma_e E^2$$

- Locally, there is power dissipation given by the product of the charge flux and the electric field.

$Q = I^2Rt$ $\Rightarrow$ Heat generated

J_e : Current density (A/m^2)

Hotplate technology



Some questions:

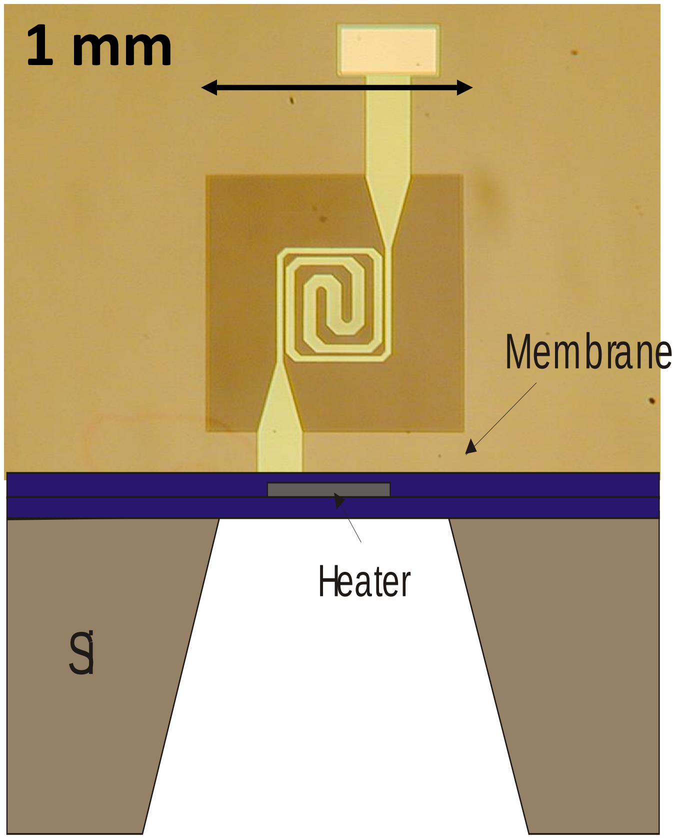
– Heating principle ?

– Heat loss mechanisms ?

– Design parameters to minimize power?

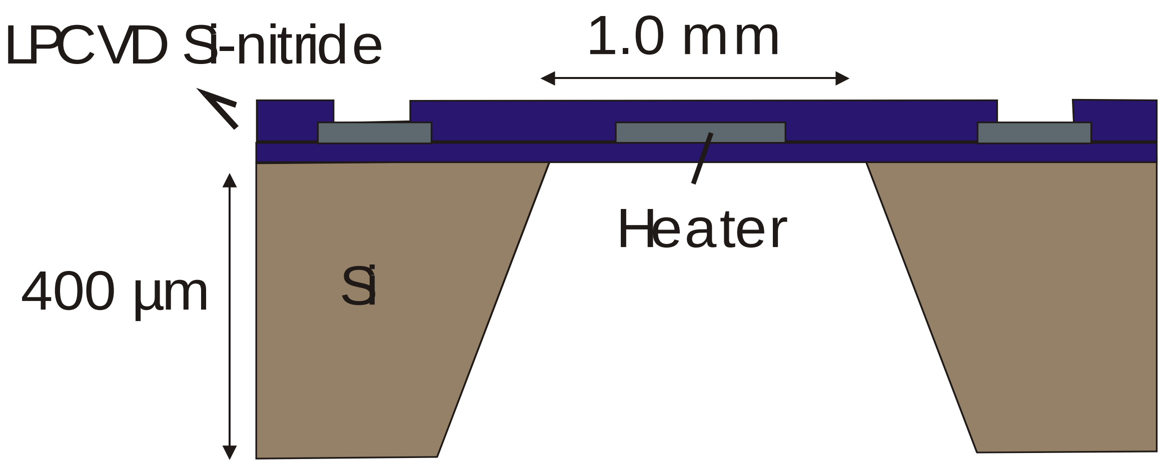
Micromachined-hotplates on Silicon

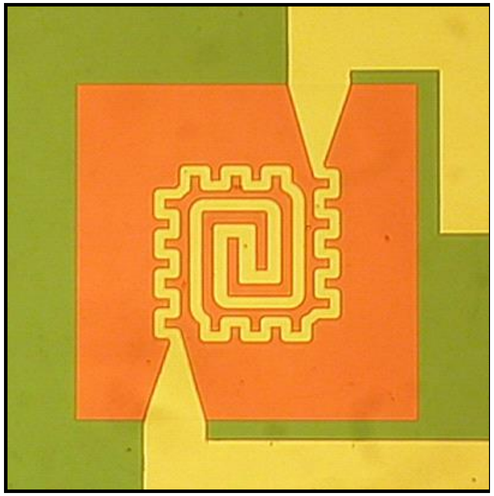
- Joule heating element (resistor) suspended on a thin (~ µm) dielectric membrane (low *k*) for thermal insulation



- Low-power consumption (mWs)
- Arrays formation
- Small thermal mass (temperature cycling: 1-100ms)
- Electronics integration with CMOS technology
- Low-cost

Micro-hotplates: Fabrication

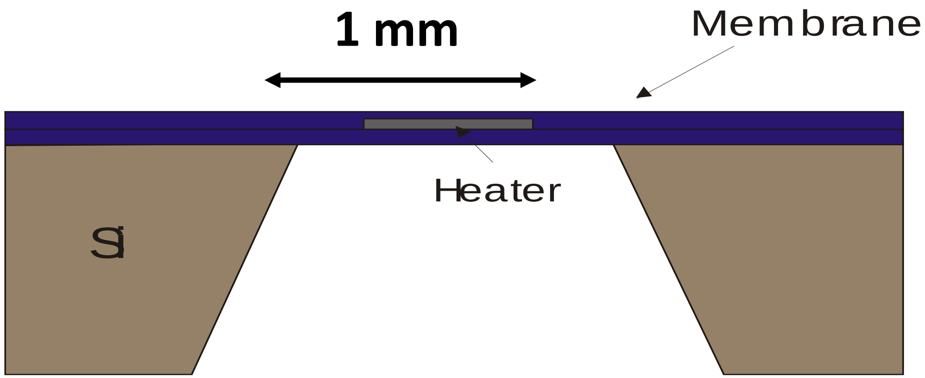


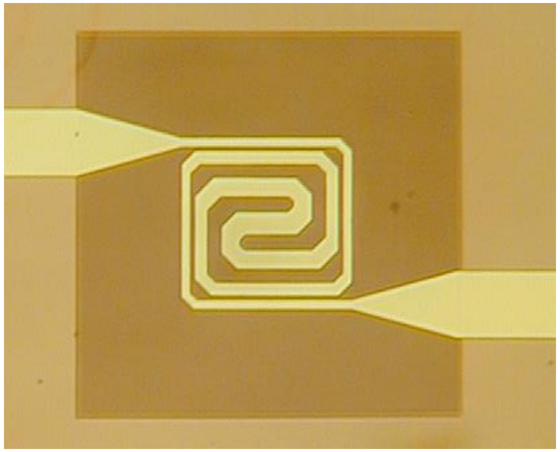


- Pt, W, Mb, Poly-Si heater (heating resistor can be used as temperature sensor since its resistance value varies with temperature)
- Membrane made of low-stress LPCVD Si_3N_4 or stack of oxide/nitride layers (low thermal conductivity and small residual stress)
- Release of the membrane using silicon bulk micromachining (KOH or DRIE)

Micro-hotplates: Design parameters

- Joule heating element (resistor) suspended on a thin (~ µm) dielectric membrane (low *k*) for thermal insulation



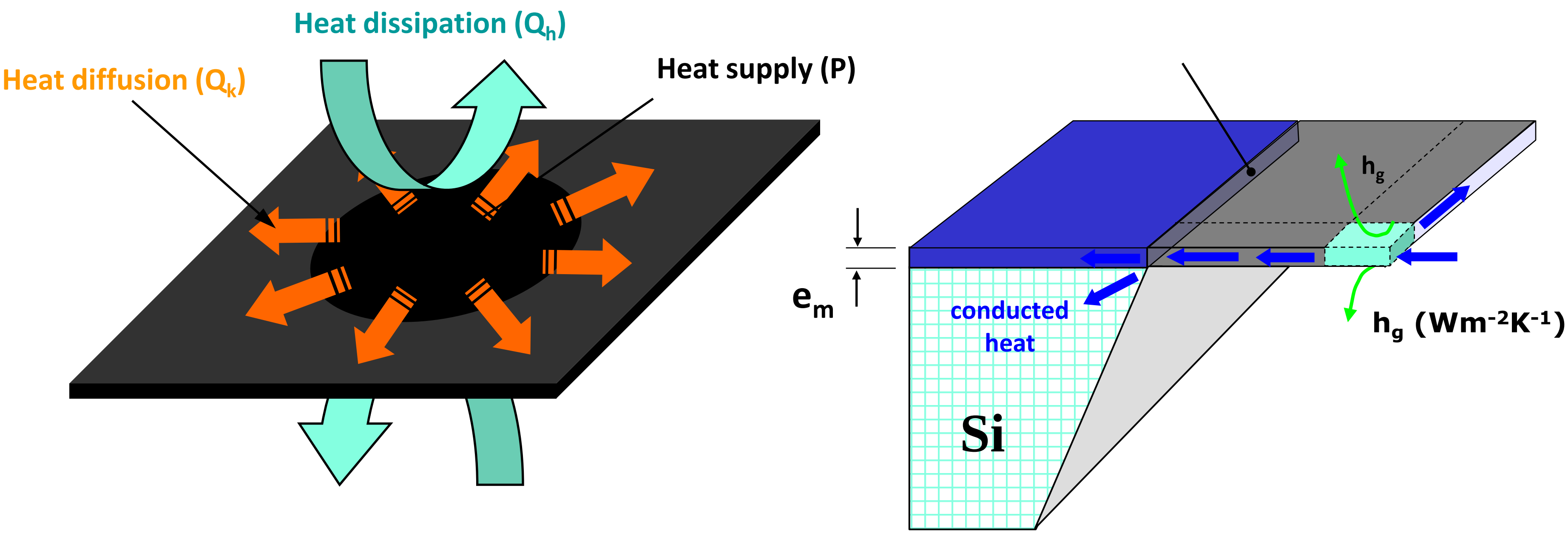


  - **Temperature distribution**: Heater lines narrower by the edges for higher heat dissipation in comparison to its center
  - **Power consumption**: Minimum heater area & thinner membrane
  - **Thermal insulation**: ratio heating / membrane area (L memb / heater: 2.2) nature of the membrane material (k value: low thermal conductivity)

Micro-hotplate: Thermal analysis

Thermal analysis of micro-hotplate ⇔ steady-state thermal balance of the membrane

[Internal heat supply] + [Heat conduction losses] + [Heat convection-radiation losses] = 0



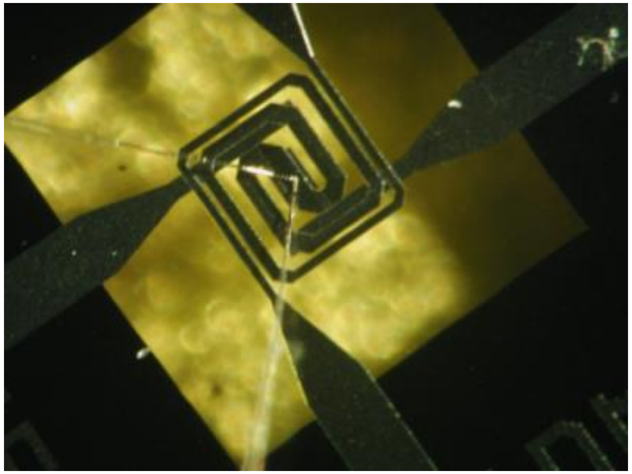
Thermal design supported by finite element modelling (FEM) simulations (COMSOL, ANSYS)

<u>For good thermal insulation</u>: ratio membrane / heater length of 2.2

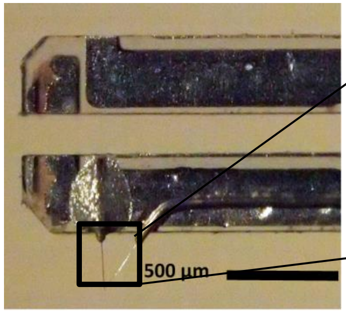
Micro-hotplate: Thermal analysis

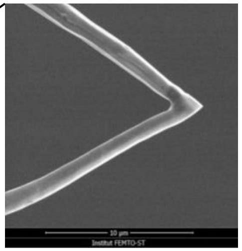
- Using micro-thermocouples (micrometric diameter)
- Or visible-NIR-IR thermal cameras (emissivity calibration)

Micro-thermocouple Pt-PtRh

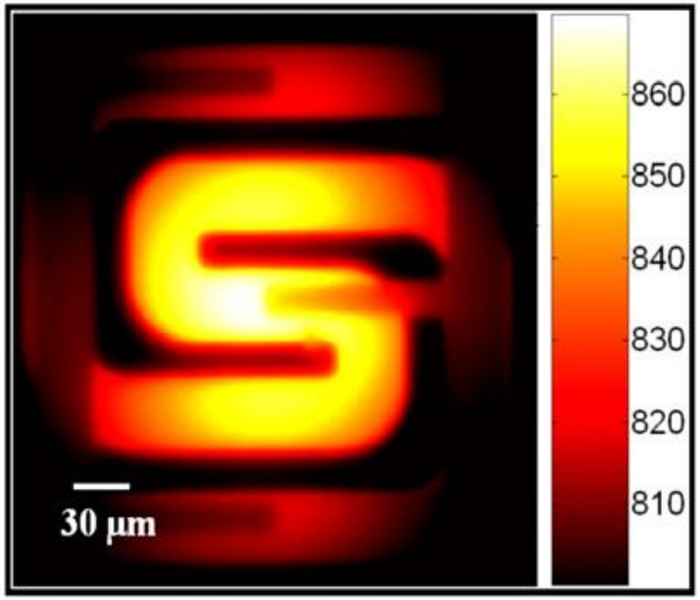


From FEMTO-ST, Besançon, France





Probe diameter
1.3 µm or 5 µm



Thermal image (visible and NIR)

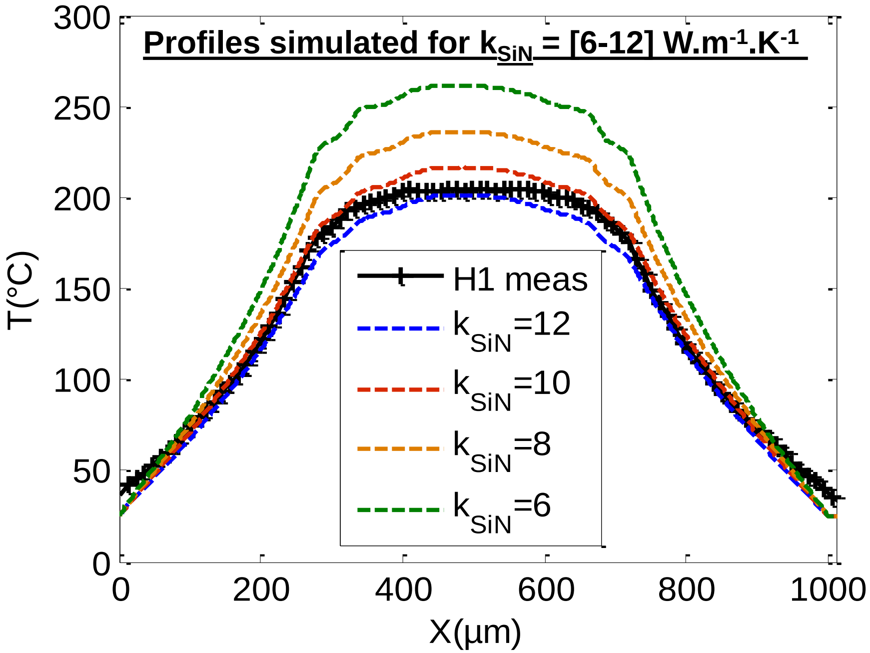
- Higher resolution, < 500 nm

Micro-hotplate: Thermal analysis

- **Simulations to predict thermal characteristics and comparison with experiments**
  - Optimisation of heat distribution and power consumption

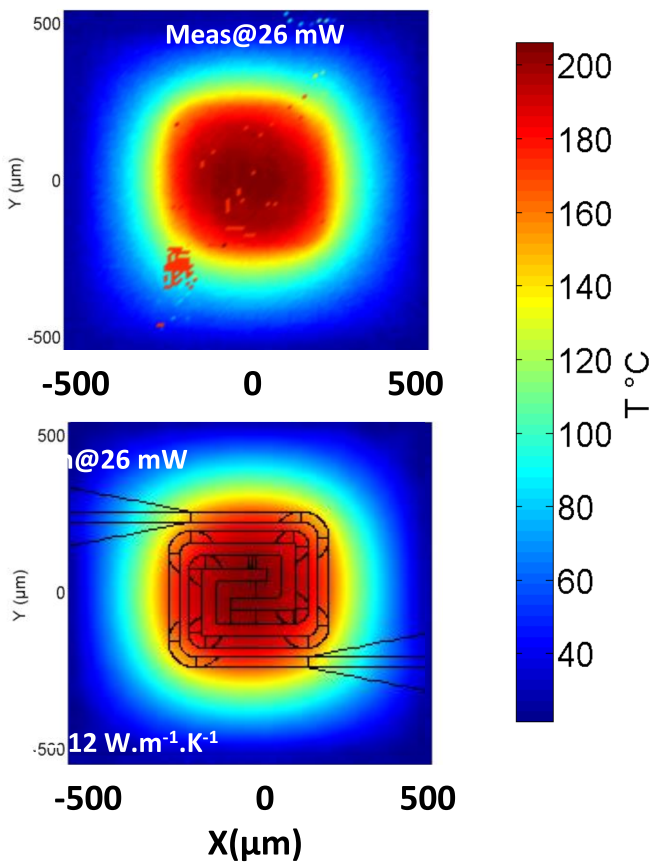
In FEM model:

- Physical parameters of materials (k, C_p)
  k: thermal conductivity (W/mK), C_p: Specific heat (Kgm²/Ks²)
- Convection coefficient h (W/m²K)
- Power dissipated by heater



Temperature distribution on the cross-section of the membrane for a given dissipated power (26 mW) by the heater

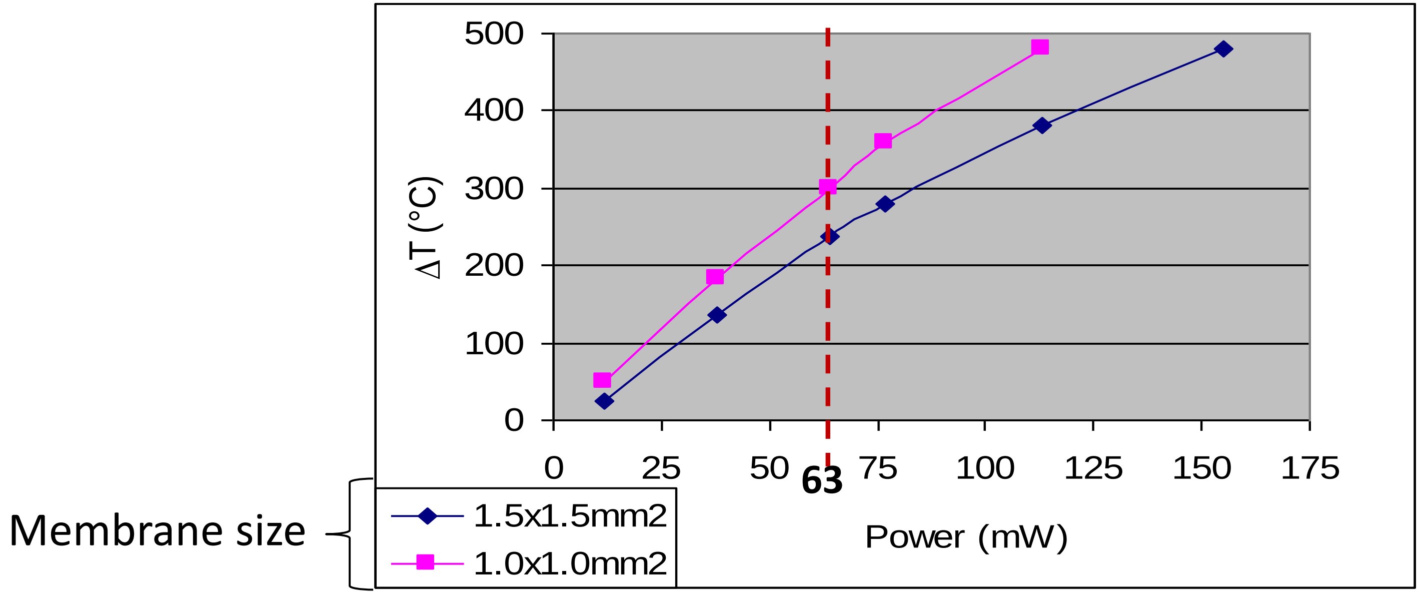
Micro-thermocouple



FEM with COMSOL

Micro-hotplate: Thermo-electrical characteristics

- Thermal time constant (to rise temperature up and down): 10 to 20 ms
- Power consumption SoA @ 300°C: 10-20 mW, by pulsing temperature: sub-mW
- Failure modes: Electromigration and/or Membrane cracking
  - Current density $J = I/A < 1 \times 10^6$ Amp/cm^2 with A: cross-section area of the electrical conductor
  - Minimize stress concentration on heater area in relation to membrane deformation: electro-stress migration



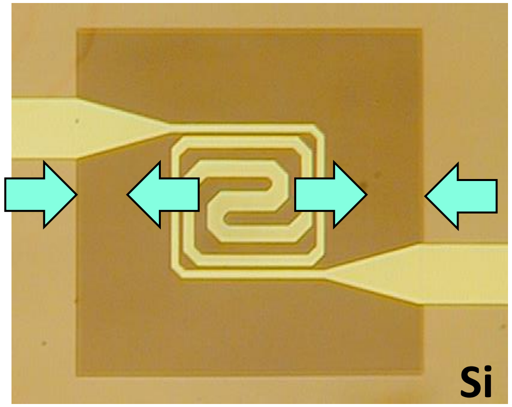
Heating area width:
- 1.5 x 1.5 mm^2: 750 μm
- 1.0 x 1.0 mm^2: 450 μm

Smallest heater width on market: 80 μm resulting in 10-20 mW of power at 300°C

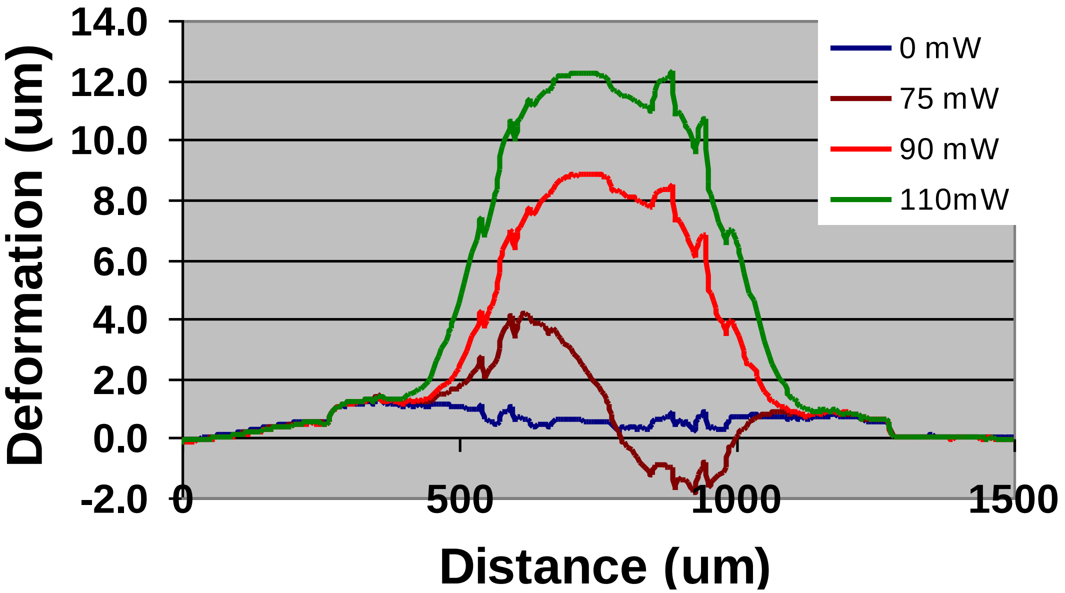
Micro-hotplate: Thermo-mechanical characteristics

- Expansion of the heated area of the membrane
- Membrane gets in compression because clamped by the silicon frame
- Membrane buckles to release stress
- To minimise compressive stress while heating, membrane should be in a tensile state after fabrication

$1 \times 1\ mm^2$, 0.75 µm-thick silicon nitride membrane

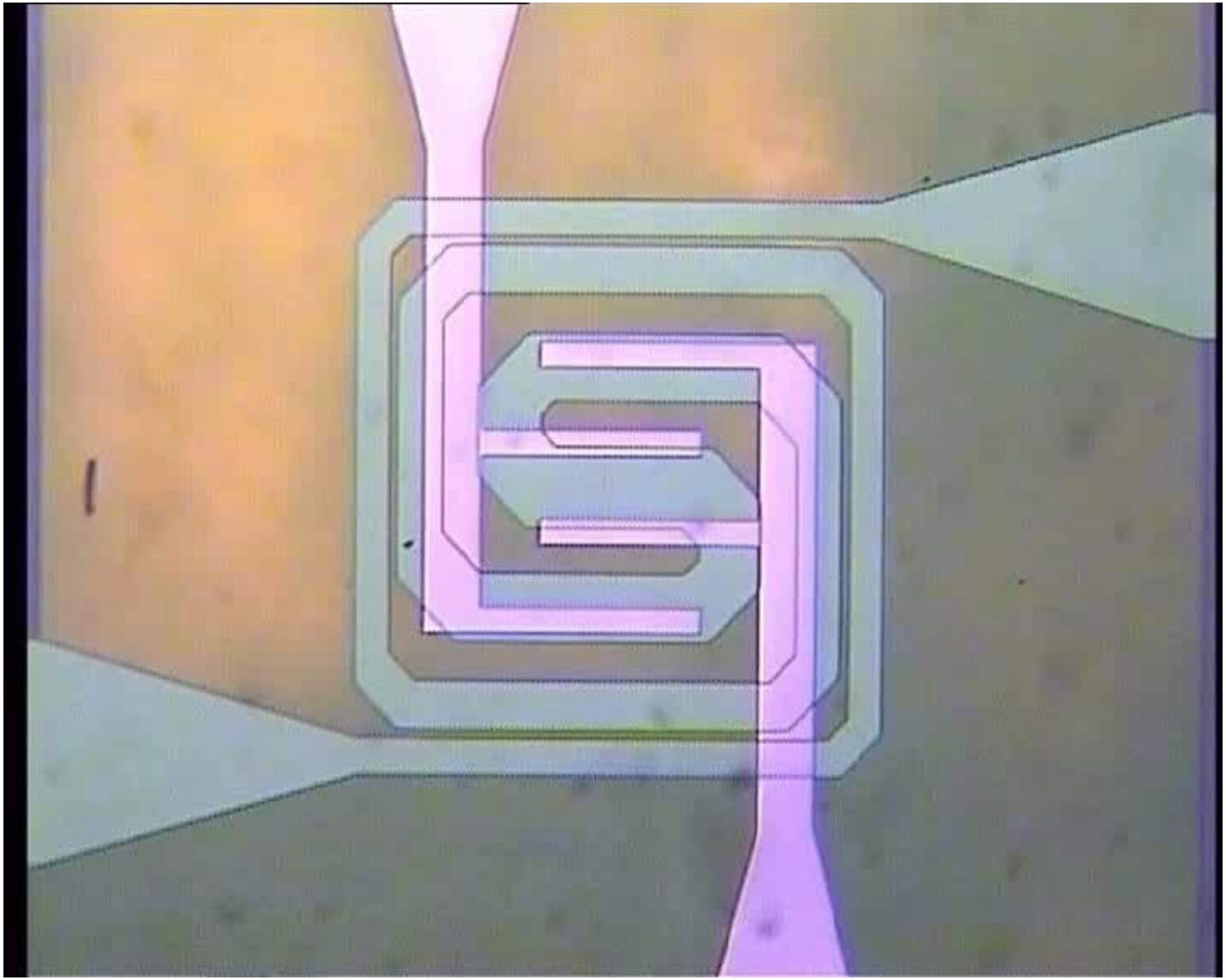


Compression rising up while heating up



Micro-hotplates: Reliability

Ramping up the operating voltage / power dissipated until break down



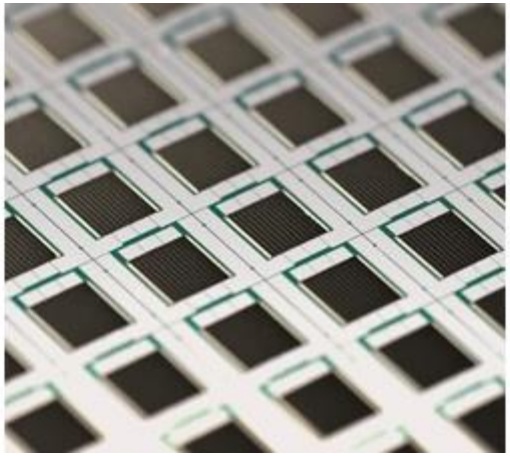
Infrared emitters

- **An infrared (IR) emitter is a source of light energy in the infrared spectrum**
  - Light emitter diodes (LED) to MEMS emitters for gas sensing applications

- Axetris IR sources are micro-machined, electrically modulated thermal infrared emitters featuring true blackbody radiation characteristics, low power consumption, high emissivity and a long lifetime.
- Reduced size, cost and power consumption

Benefits

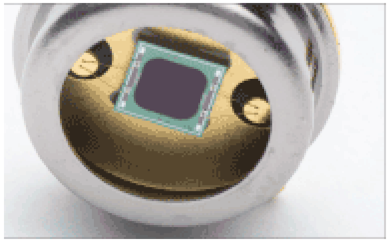
- True black body radiation (2 to 14 µm)
- High emissivity (extra coating)
- Fast electrical modulation (no chopper wheel needed)
- High modulation depth
- High electrical input to optical output efficiency
- Low power consumption
- Long lifetime



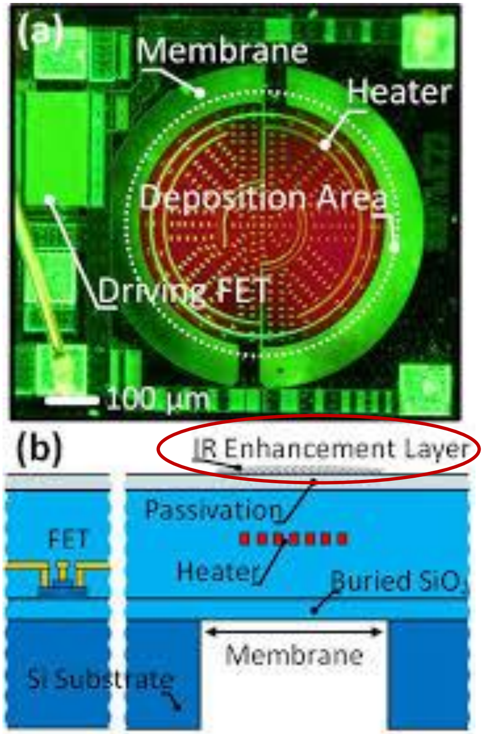
emitting area is 0.8x0.8 mm^2

Infrared emitters

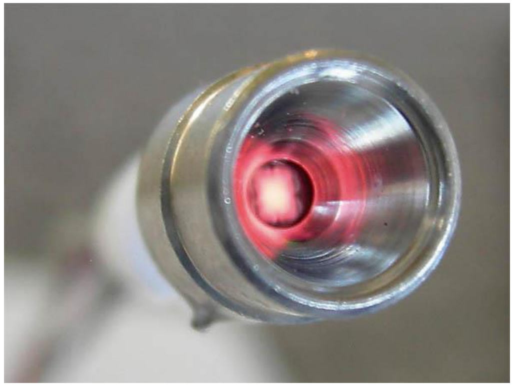
- Operating principle
  - Joule heating (500°C and more)
  - Thermal insulation using micro-hotplate design
  - Coated with black emissive layer (emissivity ≈ 1)
  - Optical reflectors for higher intensity
  - 2 – 15 µm mid IR waveband



CCMOS Sensors

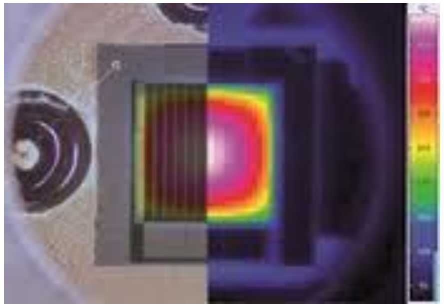


$$Q = \varepsilon \, \sigma \, T^4 \, A$$



Axetris

CCMOS Sensors
using SOI wafer
and CMOS process
Heater: W

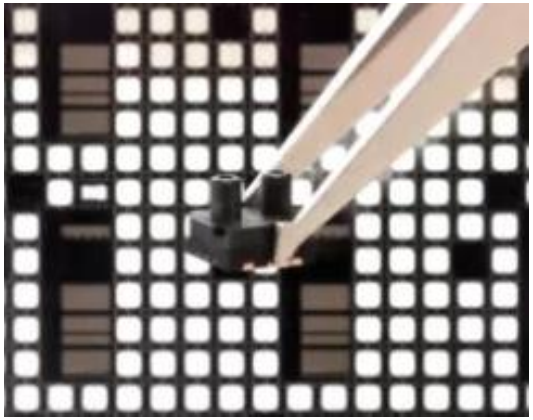


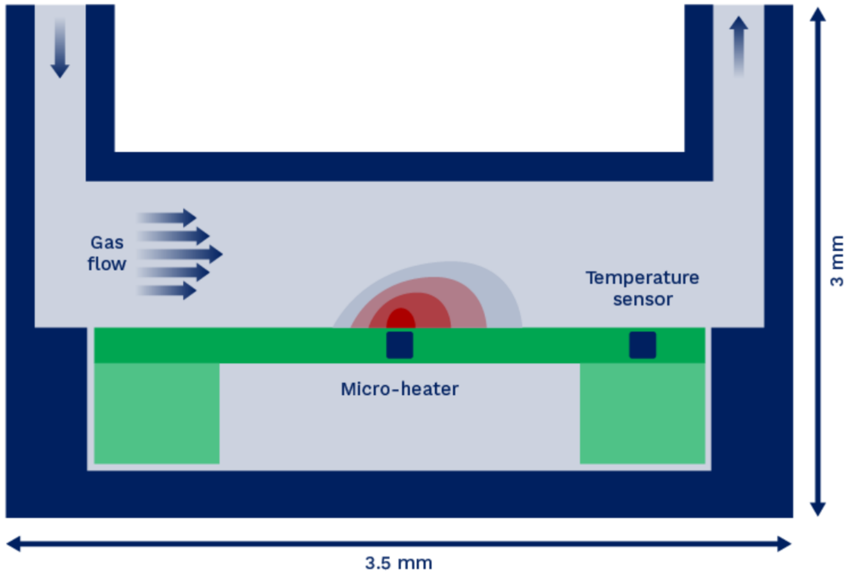
Thermal flow sensors and accelerometers

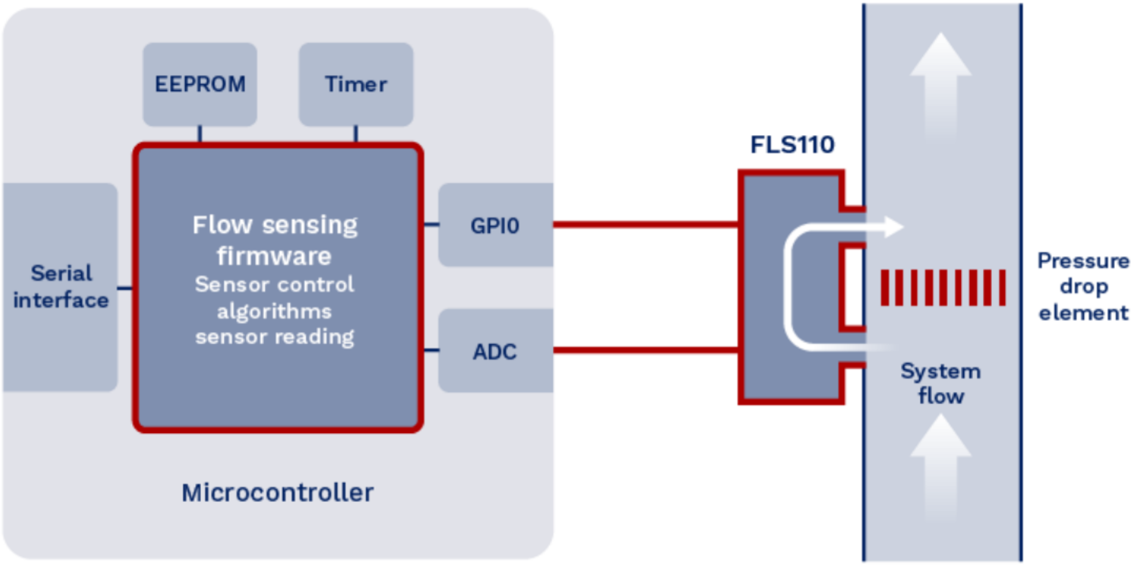
Thermal flow sensors

- Flusso CMOS digital flow sensor

Smallest air velocity sensor





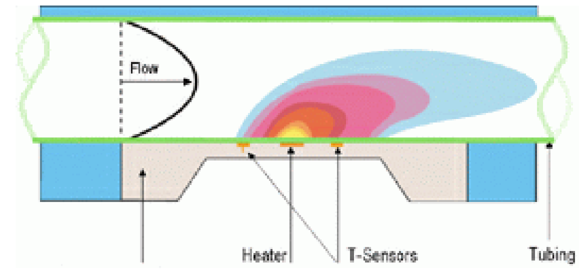


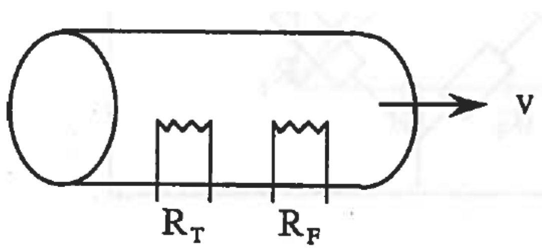
https://flussoltd.com/technology

In red: solution supplied by the company

Thermal flow sensors

- Operating principle
  - Based on heater and temperature detection
  - Flow will create a temperature difference between the temperature sensor(s) and the heat source





R_T in equilibrium with the fluid
R_F heated to a temperature > fluid temperature

Power exchanged in the fluid by convection: $P_{out} = hA\Delta T$ h: convection coefficient
A: heating area

King empirical relation: $h = a+b\sqrt{v}$ a & b: constants for given fluid and sensor

$P_{out} = (A+B\sqrt{v})\Delta T$

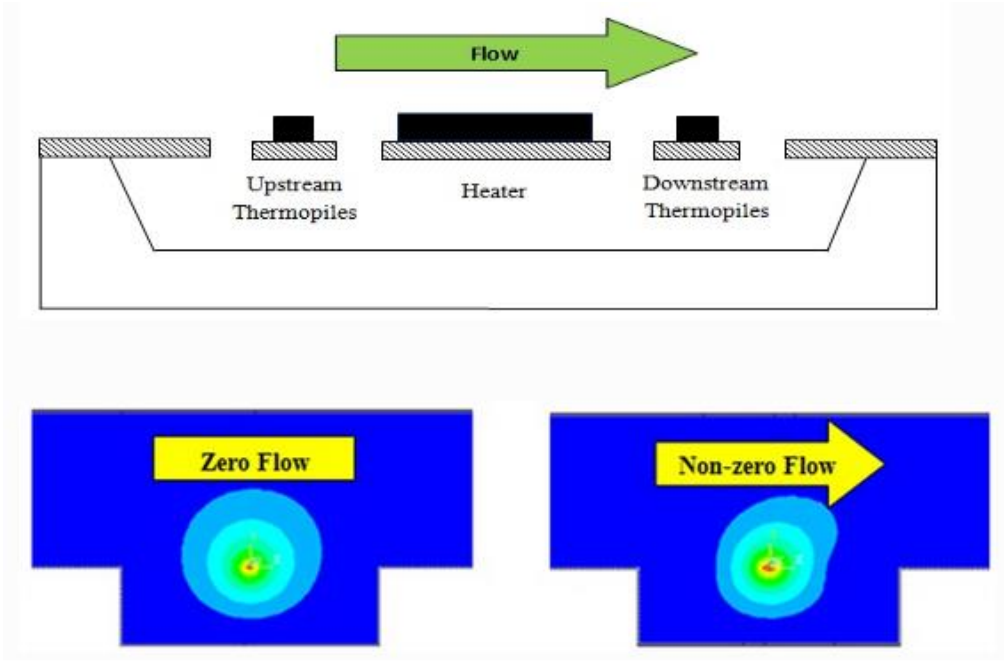
At thermal equilibrium $P_{in} = P_{out} \Rightarrow$

$$v = \sqrt{\left(\frac{R_F(T)I^2}{\Delta T} - A\right)\frac{1}{B}}$$

$P_{in} = R_F(T)\,I$
power dissipated in resistor R_F is a function of current I at given T°C

Thermal flow sensors

- CMOS digital flow sensor from MEMSIC (China)



Measurement of the temperature difference between the two thermopiles (several thin film Al-PolySi thermocouples)

- Holes in the membrane for better thermal insulation from the substrate and more efficient heat transfer in the fluid

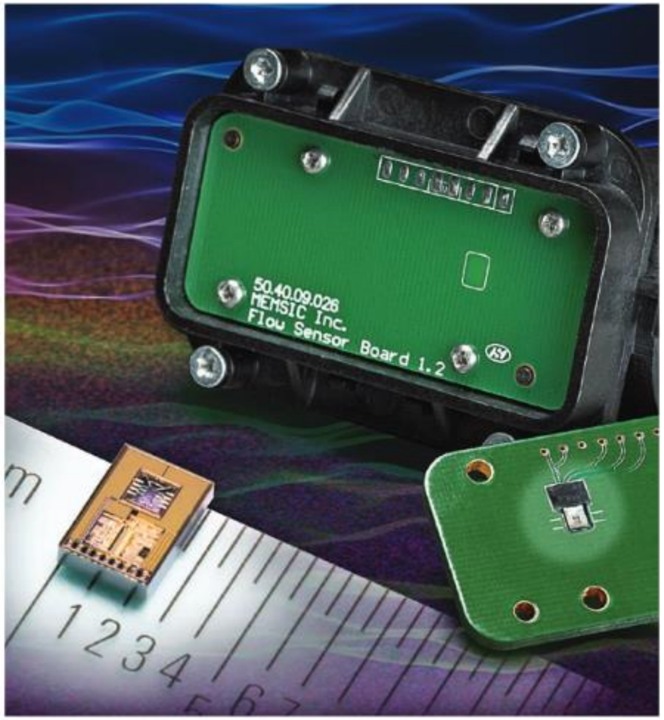
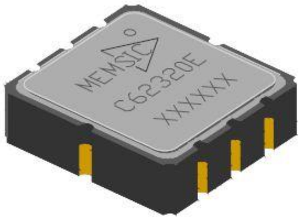


Fig. 1: The MFA1100R thermal gas-flow sensor module integrates the sensing element with on-chip signal-processing and software on a monolithic CMOS process.

Thermal accelerometers

- CMOS thermal accelerometers from MEMSIC (China)

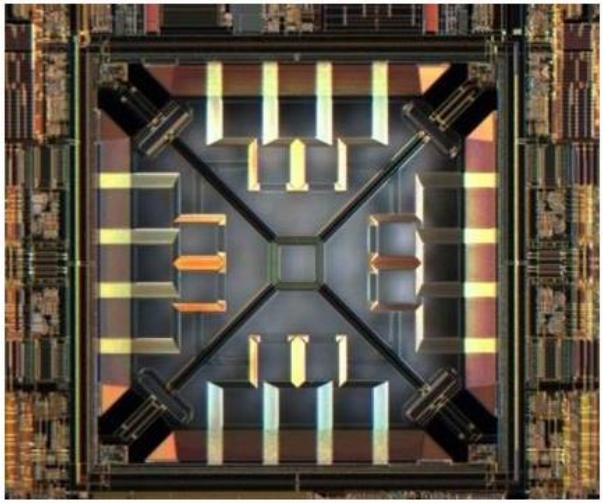
MEMSIC accelerometers and tilt sensors are shipped into millions of automobiles and consumer products every year.



MEMSIC's unique thermal technology uses heated gas molecules to detect acceleration.

This technology offers several advantages over the solid proof-mass structure, including:

- No measurable resonance (immunity to vibration)
- Virtually indestructable (50,000g shock tolerance)
- No stiction
- No detectable hysteresis
- Excellent zero-g offset stablity
- Sensor & electronics integrated onto monolithic IC



http://www.memsic.com/accelerometers

However compared to capacitive accelerometers:

- High power consumption
- Lower bandwidth and lower g

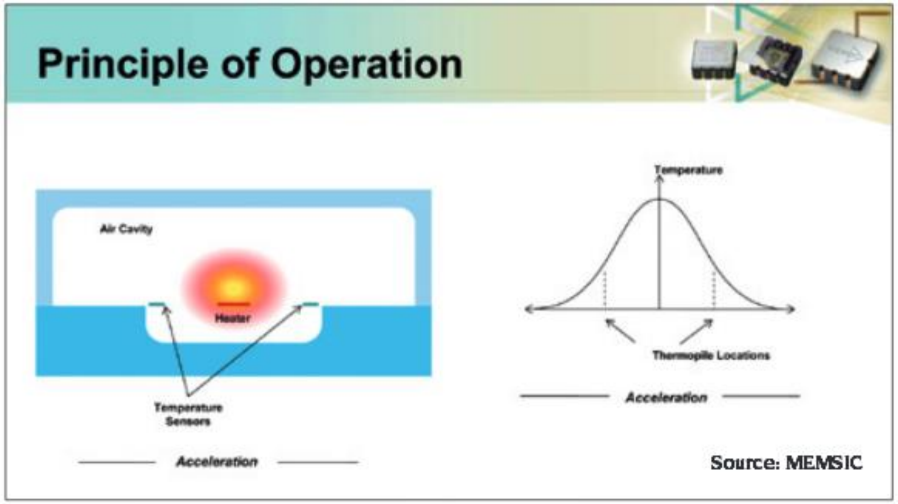
Thermal accelerometers

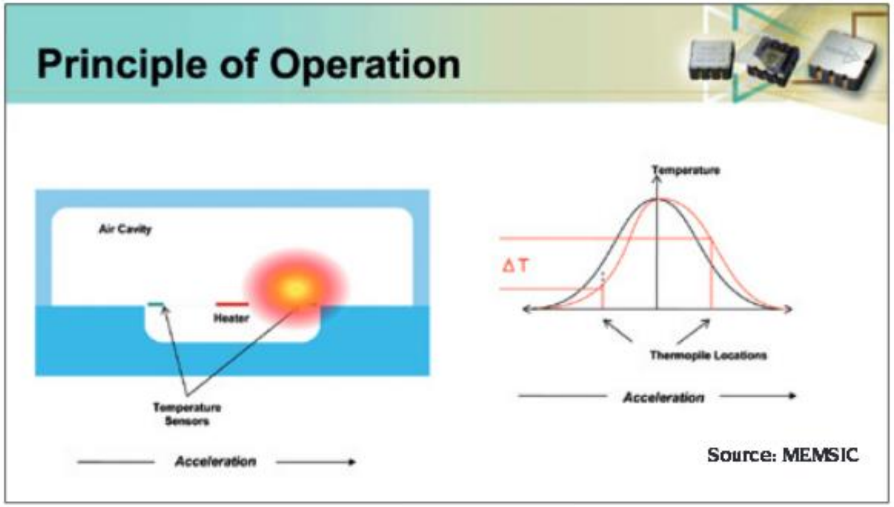
- CMOS thermal accelerometers from MEMSIC (China)

- Centrally located resistive heating element to heat the gas molecules and temperature sensors such as thermocouples to measure the temperature difference between the time when there is no acceleration and when acceleration is applied.

- When subjected to acceleration, the less dense air molecules in the heated gas move in the direction of acceleration and the cool and denser molecules move in the opposite direction, creating a temperature difference.

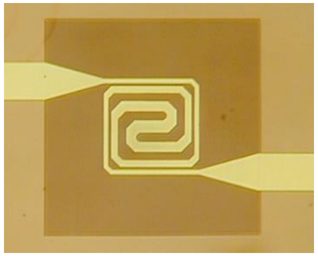
- The temperature from one side of the MEMS structure to the other is proportional to acceleration

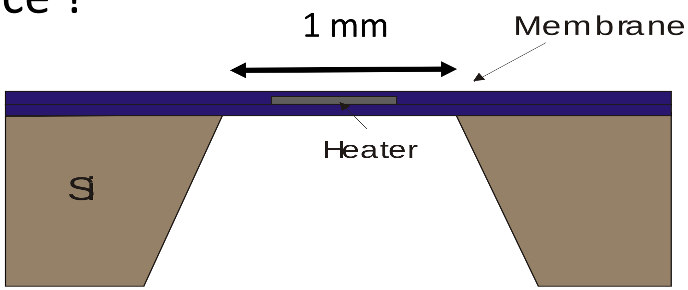




Some questions:

- Important design parameters to minimize power ?
- How to tune the heat distribution over the surface ?
- How to maximize their lifetime ?





Fundamentals of Chemical Gas Sensors

Content Chemical Gas Sensors

- Introduction
- Definitions
- Thermal
- Chemoresistive
- Chemocapacitor
- Optical

Chemical sensor: Definition

"A chemical sensor is a device that transforms chemical information, ranging from the concentration of a specific sample component to total composition analysis, into an analytically useful signal".

by IUPAC (International Union of Pure and Applied Chemistry)

Transducer

Transducer is derived from Latin *"transducere"*, which means to "transfer or translate". Therefore, a device that translates energy from one kind of system (e.g., chemical) to another (e.g., physical) is termed a transducer.

Chemical sensors: Tasks

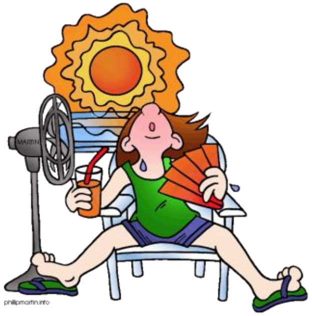
- obtain qualitative and/or quantitative time- and spatially resolved information on specific chemical components

- *qualitative information:* presence or absence of certain odorant, toxic, carcinogenic or hazardous compounds

- *quantitative information:* concentrations or partial pressures of specific compounds

environmental

health



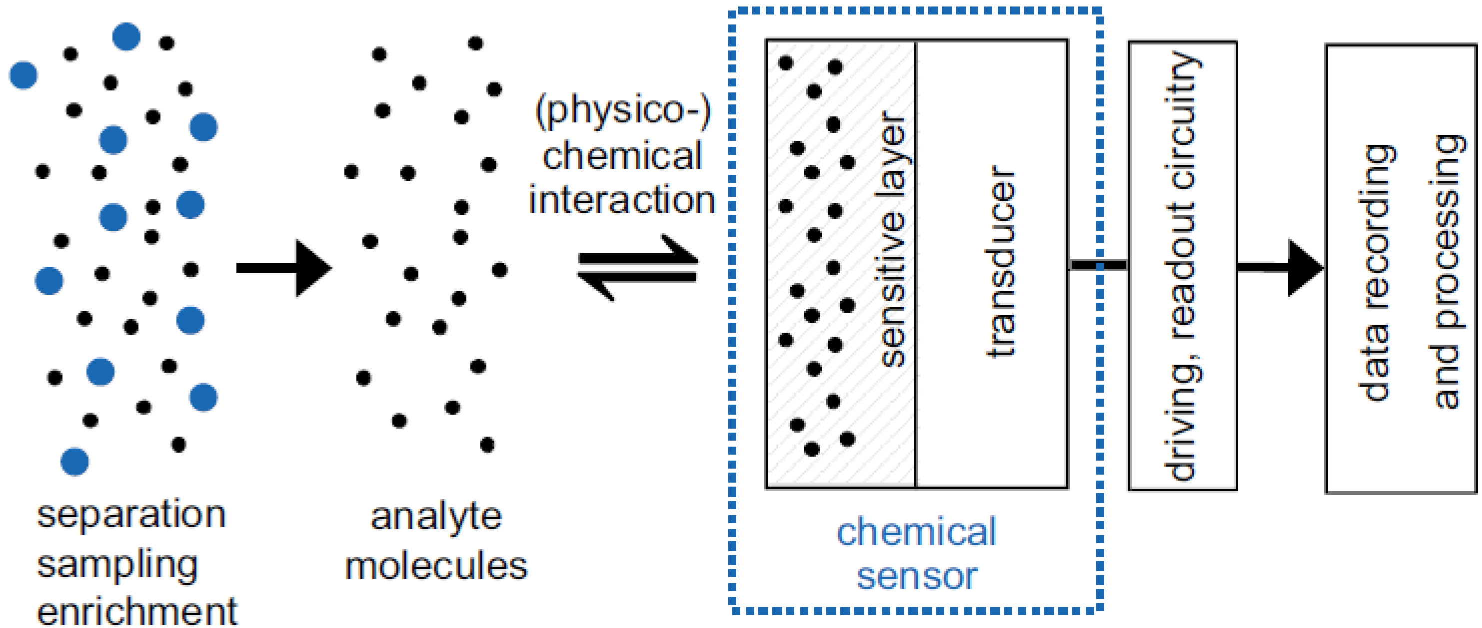
comfort

Safety / security

Gas sensors: Interaction mechanisms

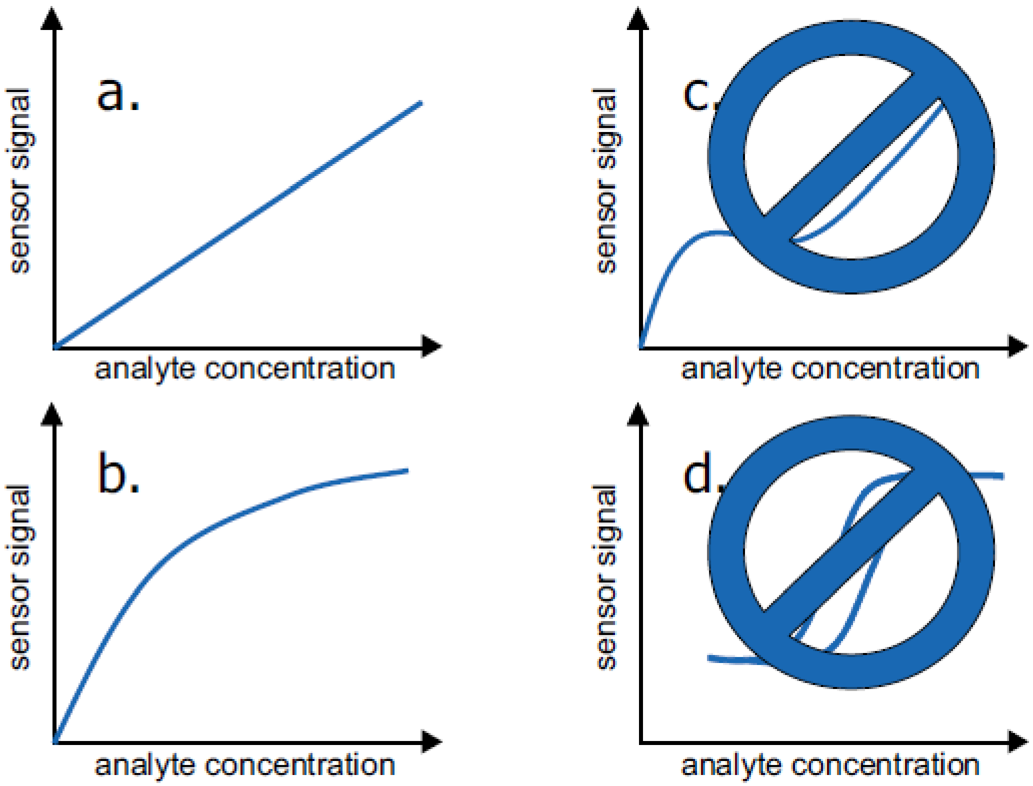
- Different types of chemical interaction in chemical sensing process: range from very weak *physisorption* through rather strong *chemisorption* to charge transfer and chemical reactions.
- Physisorption: only physical ab/adsorption (London dispersion forces) with interaction energy of 0 – 30 kJ/mol
- Chemisorption: much stronger, interaction energy > 120 kJ/mol. Particles stick to surface/volume by forming chemical (usually covalent) bond.
- Ionosorption: delocalized chemisorption with charge exchange to the conduction / valance band.
- Charge transfer and chemical reactions involve interaction energies comparable to chemisorption and higher.

Chemical sensor system

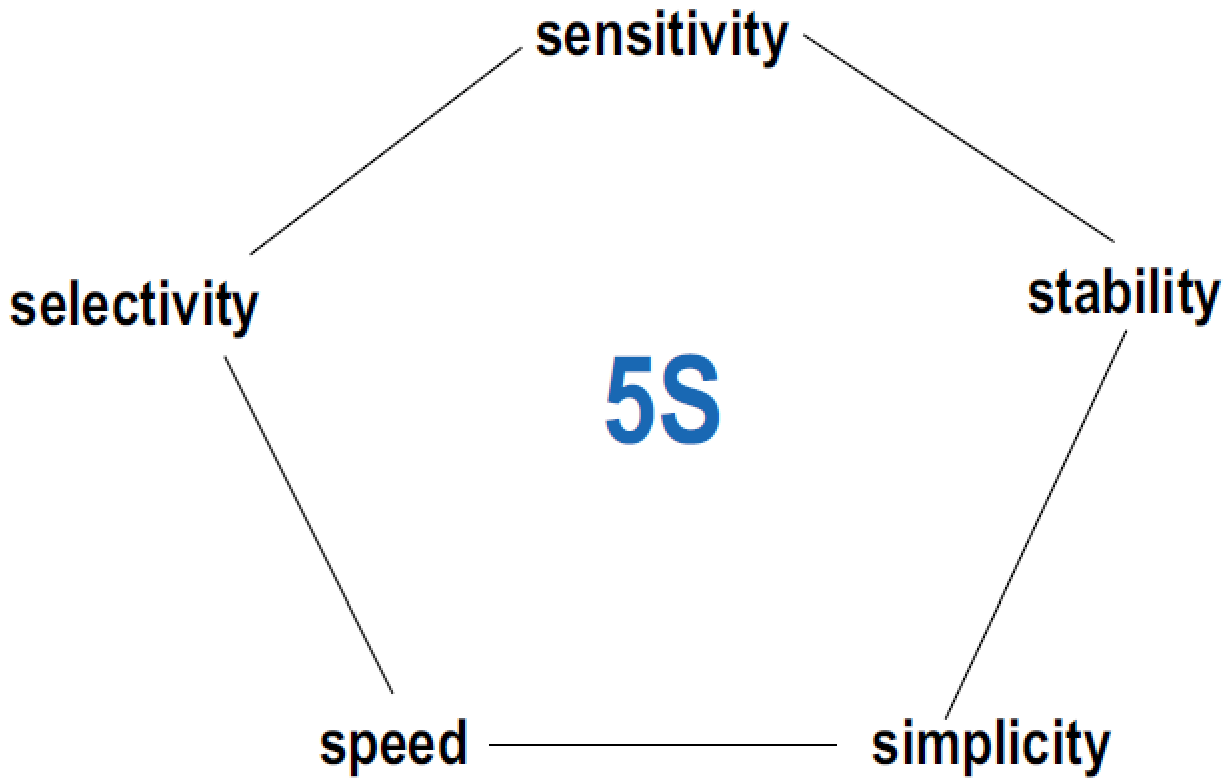


Chemical sensor: Signal

Response curve fct. concentration



Chemical sensor: Requirements



Chemical sensor: Sensitivity

Sensitivity

is the slope of the analytical calibration curve, i.e., how large is the change in the sensor signal upon a certain change in the analyte concentration.

The sensitivity is the derivative of the response curve. For a non-linear response curve as in Figure b in slide 34, the sensitivity is function of the measurand value.

Limit of Detection (LOD)

corresponds to a signal equal to *k*-times the standard deviation of the background noise (i.e. *k* represents the signal-to-noise ratio) with a typical value of $k = 3$.
Values above the LOD indicate the presence of an analyte, whereas values below LOD indicate that no analyte is detectable.

Requirements

- *High sensitivity and low LOD (limit of detection)*
- *Large dynamic range*

Chemical sensor: Selectivity

Cross-Sensitivity

Cross-sensitivity hence refers to the contributions of other than the desired compound to the overall sensor response.

Selectivity/Specificity

Selectivity is the ability of a sensor to respond primarily to only one chemical species in the presence of other species (usually denoted interferants).

Requirements

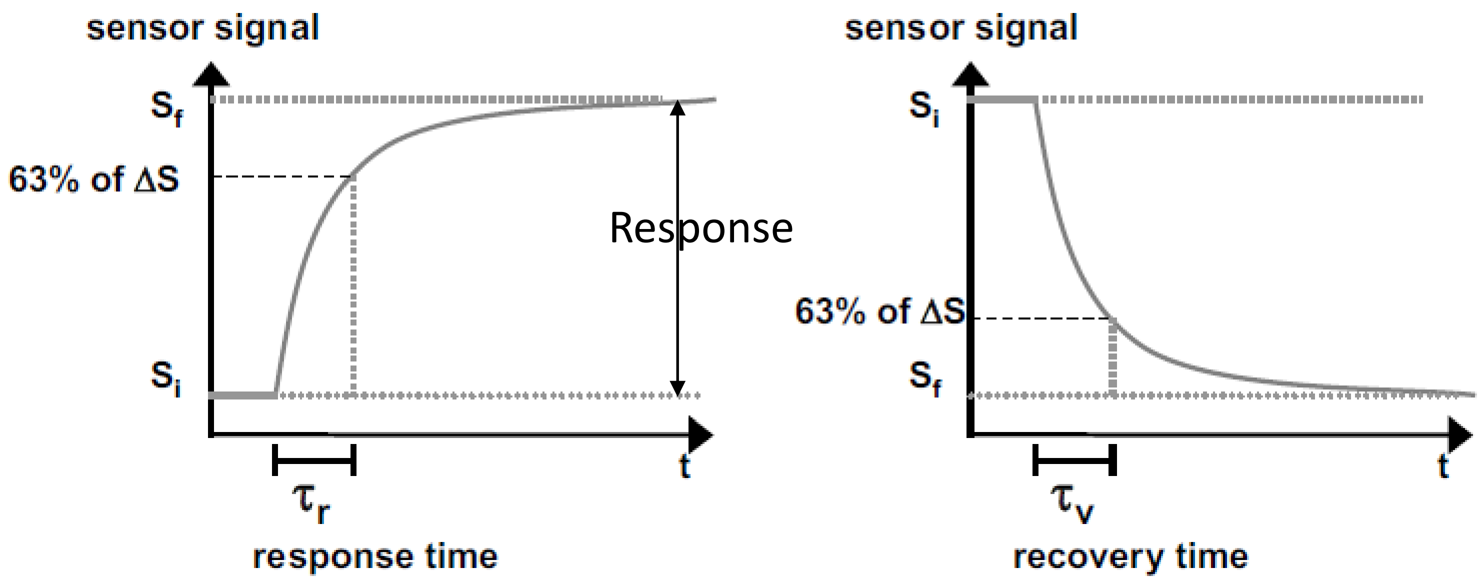
- *High selectivity to target analyte and low cross-sensitivity to interferants*

Chemical sensor: Speed

Response curve fct. time

Requirements

- *Short recovery and response times*



Another definition: 90% of the time to reach the steady-state signal

Gas sensors: Categories

Analyte (CO, NOx, EtOH, H_2O, VOCs ...)

Oxidising and reducing gases / VOCs: Volatile organic compounds

Sensing Material (Metals, Polymers, Metal Oxides, Ionic compounds ...)

Remark: There are chemical sensors without sensing materials !

Transduction principle:

(1) Chemomechanical Sensors (mass, viscosity, stress ..)

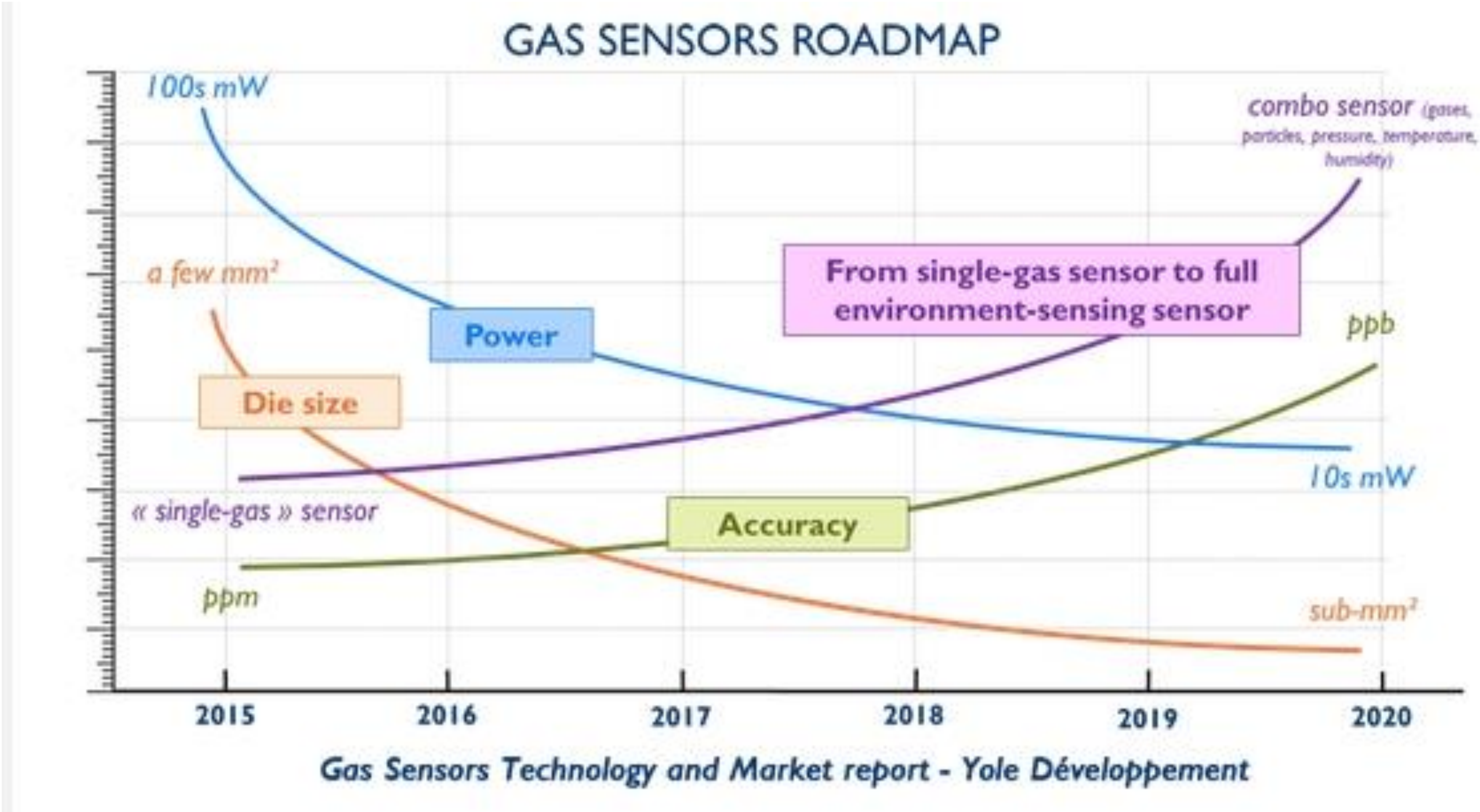
(2) Thermal Sensors (temperature, heating power …)

(3) Optical Sensors (intensity, wave length, polarisation …)

(4) Electrochemical Sensors (potential, current, resistance …)

Microfabricated Gas Sensors

MEMS gas sensors: Status and perspectives



Miniaturized gas sensors

Microsystems based:

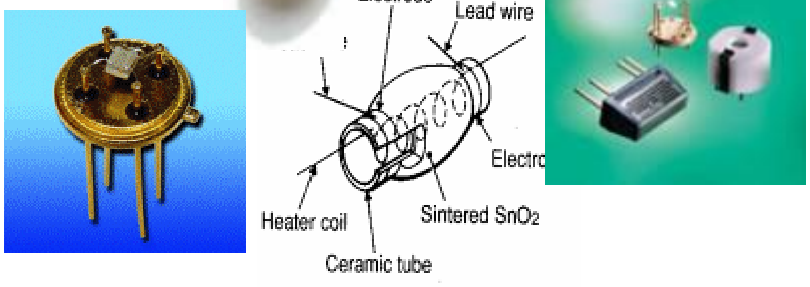
- Thermal conductivity: H_2, He, CH_4, CO…
- Pellistors (catalytic): combustible gases
- Metal-oxide semiconductor (MOS): CO, NO_x, Hydrocabons, VOCs
- Optical IR and photoacoustic sensors: Mainly CO_2

Not addressed in this lecture:

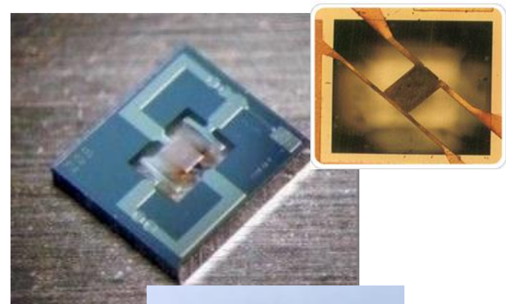
- Resonators: was addressed in Guillermo's lectures
- Field-effect (catalytic): Hydrogen containing molecules
- Electrochemical cell: CO, CO_2, NO_x, O_2, H_2, CH_4, H_2S, selective sensors but not silicon based

Miniaturized gas sensors

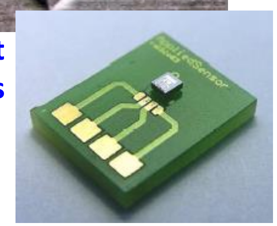
Semiconducting Metal oxides, Classic ceramic set-up (Figaro, FIS, UST, IST)



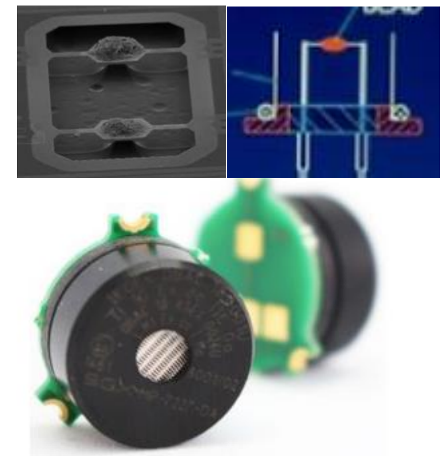
Semiconducting Metal oxides (MOS) (AMS, SGX-Sensortec, Seju, Figaro, Sensirion)



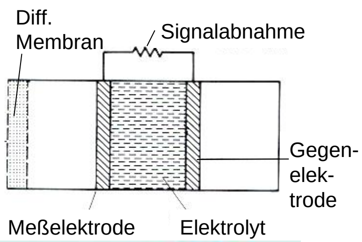
Field-effect catalytic sensors



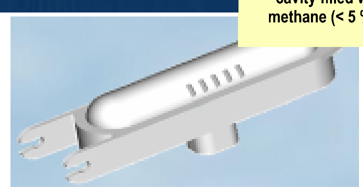
Calorimetric Sensors (Sixth Sense, SGX-Sensortec)

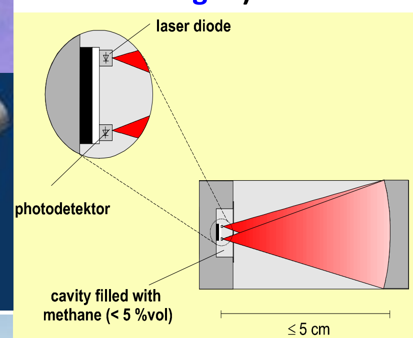


Electrochemical Cell (not microsystems based) (AlphaSense, Dräger, E2V, Sixth Sense)

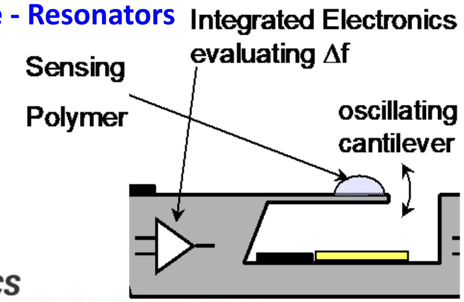


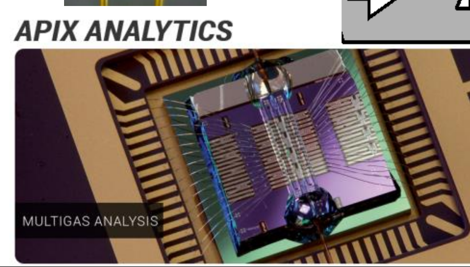
IR-Adsorption (Bosch, Tyco, CCMOS Paragon)



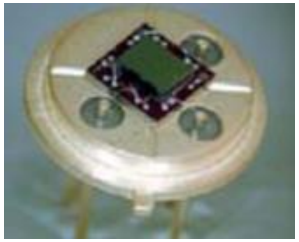


Microbalance - Resonators (AMS, APIX)





Thermal conductivity detector (TCD)

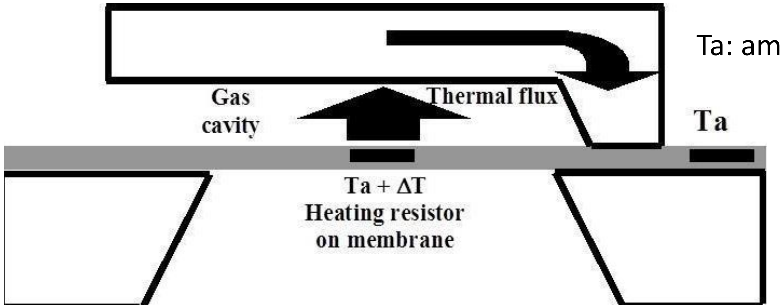


From Endetec (CH)

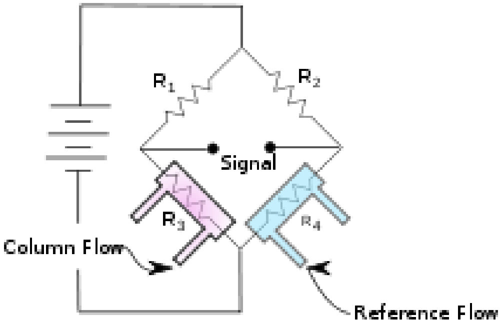
- This detector senses changes in the thermal conductivity of surrounding atmosphere. Use for H_2, CH_4, CO_2

- Operating principle is based on thermal flow transfer from a heated resistor located on an isolated dielectric membrane to the cold part of the device. Thermal flow is directly depending on the gas conductivity.

  The principle is based on the signal measurement of the ratio Rm/Rt, Rm resistance located on the heated part of the device, Rt is a resistance located on the "cold" part of the device at room temperature. Such approach allows a first order temperature compensation of the signal.



Ta: ambiant temperature



Design trade off for the heating area for optimum sensitivity: heat exchange by convection in gas vs. conduction in membrane.

In gas chromatograph, helium used as carrier gas with two sensing chambers: column (with gases to be detected and reference (only carrier gas)

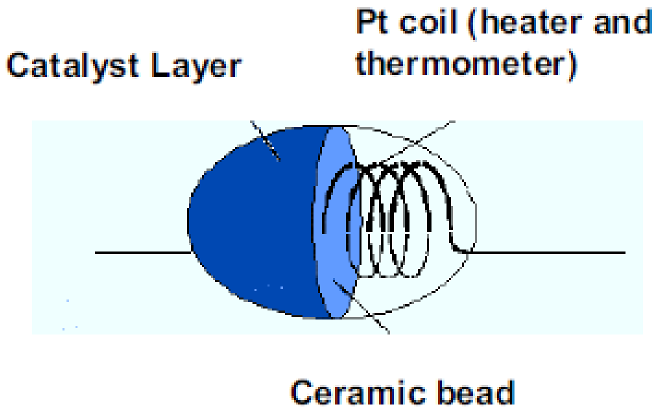
Catalytic

- detect analyte-induced enthalpy changes.
- chemical reaction or even physisorption releases or absorbs from its surroundings a certain quantity of heat (enthalpy, ΔH^0).
- reactions liberating heat: *exothermic*, abstracting heat: *endothermic*.
- heat shows transient behavior: continuous liberation/abstraction occurs only as long as reaction proceeds.
- *steady state* situation: chemical reaction proceeding at constant rate.
- no heat production and no measurable signal at thermodynamic equilibrium ($\Delta G = 0$) (in contrast to: mass-sensitive, optical, electrochemical sensors).
- liberation or abstraction of heat measured as temperature change, easily translated into an electrical signal.

Catalytic

- Measures heat evolved during the controlled combustion of flammable gases in ambient air on the surface of a hot catalyst by means of resistance thermometer in proximity.

Pellistor

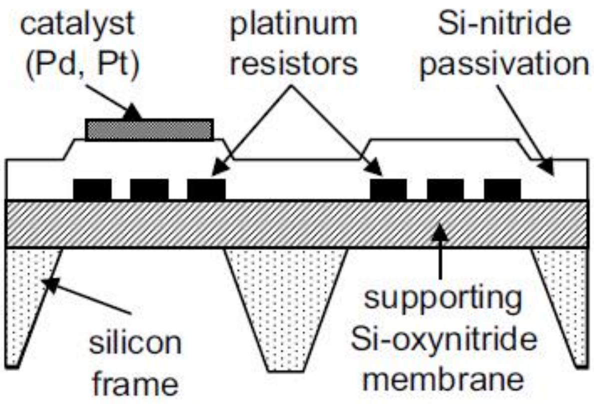


$$CH_4 + 2O_2 \Rightarrow CO_2 + 2H_20$$

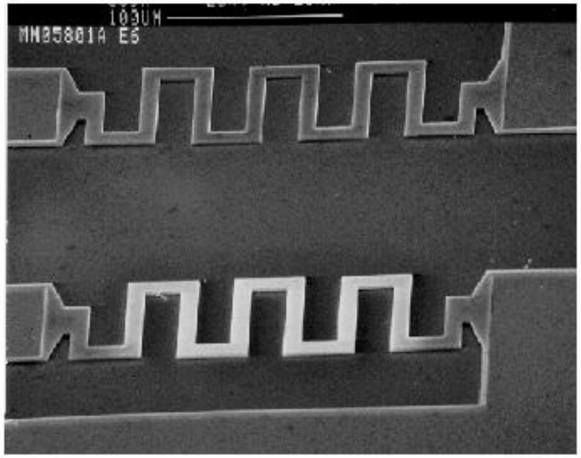
- ceramic bead (pellet) (e.g. ThO_2, Al_2O_3)
- catalyst surface layer (Pd, Pt)
- Pt-coil inside (heater and T-Sensor)
- typ. operating temperature 200-500°C
- combustible gases like CH_4, CO, ...
- operation modes:

non-isothermal: temperature change induced by reaction heat

isothermal: temperature is kept constant by providing heating power



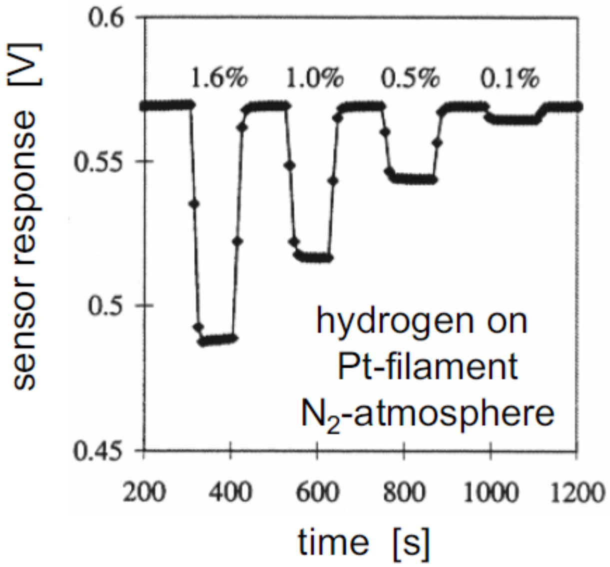
micro membrane



micro filament

Operation (Pt resistors used as heater and temperature sensor):

- Power constant and look at ΔT
- Temperature constant and look at ΔP
- Differential mode (with reference unit)

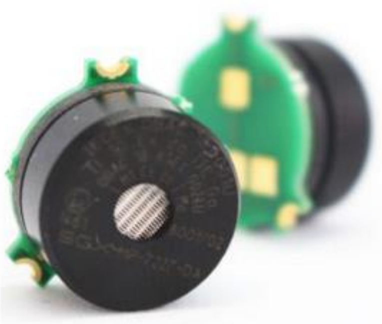


M. Zanini, et al., Sens. Actuators A 48 (1995), 187-192.

R.P. Maginell et al., Technical Digest Solid State Sensor and Actuator Workshop Hilton Head Island, SC, 1996, 23-27.

Gas sensors: Thermal catalytic

- The MP7227-DA MEMS pellistor for methane detection is a low power, extremely robust and poison-resistant device in a certified flameproof enclosure.
- The sensor provides ultra-low power consumption when used in pulse mode operation, which makes this sensor a preferred choice for battery operated devices.



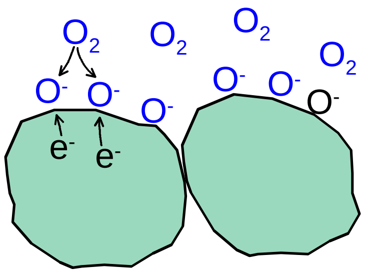
From SGX Sensortech Corcelles (CH)

Minimum sensitivity *(measured with 1% methane at 3.0 ± 0.1V)*	8 mV/% methane
Zero offset range in clean air	-30mV ± 20 mV
Response Time (T_{90}) (See Note 2)	< 12 sec
Maximum gas concentration (see note 3)	5% methane in air
Long Term Zero drift (see note 4)	< 1.0 mV / month
Long Term Sensitivity drift (see note 5)	< 0.6 mV / month

DC supply to detectors	+2.9 to +3.1V;
Typical power	37.0 to 41.0 mA (<96mA at power on)
Mode of Operation	Continuous or pulsed[1]

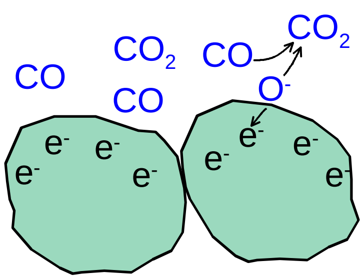
Conductometric metal-oxide semiconductor (MOS)

oxidising ambient



electron depletion at surface and grain boundaries
⇓
high resistance

reducing ambient



electron rich surface and grain boundaries
⇓
low resistance

Tin dioxide: **oxygen-deficient, n-type semiconductor** with oxygen vacancies as electron donors.

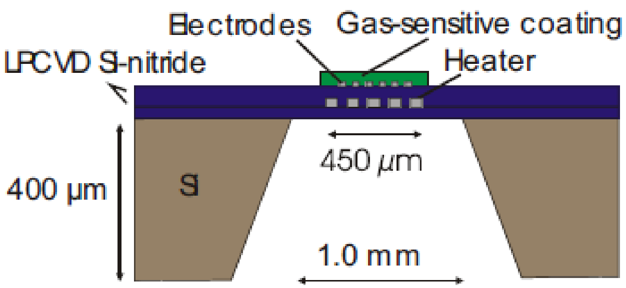
- Clean air: oxygen (traps free electrons) and water absorbed on particle surface forming potential barrier, restrict electron flow and increase resistance.
- **Reducing gases** (CO) adsorb at surface, remove oxygen in reaction with water and oxygen at surface which lower barrier and resistance. (**the opposite for oxidizing gases**)
- Metal oxide sensors are **not selective**, respond to almost any analyte (CO, nitrogen oxide, hydrogen, hydrocarbons).
- **Surface doping** with catalytic metals (Pt, Pd, Au, Ir) modifies sensitivity / selectivity, reduces response time and operation temperature.

Heated for improved kinectics of reactions in a pulse temperature mode (temperature is cycled)
- Improved sensitivity to gases (function of temperature) and response/recovery time
- Reduced effect of humidity

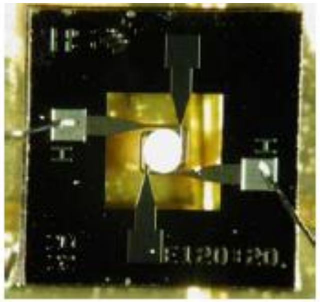
Large variety of metal-oxide materials have been evaluated (SnO_2, WO_3 being commercial)
- Thick, thin films and now nanostructures such as nanowires

Conductometric metal-oxide semiconductor (MOS)

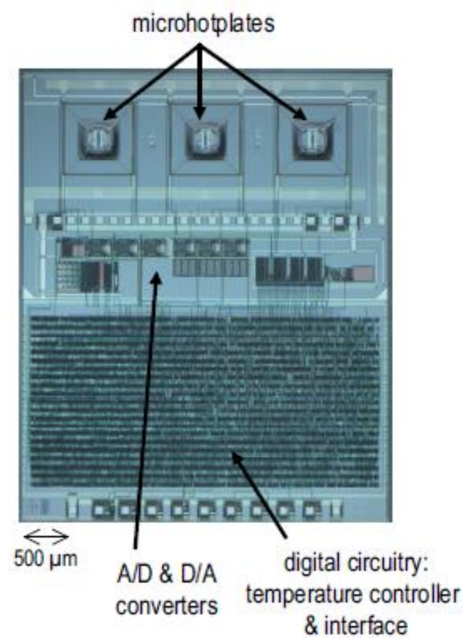
Non CMOS vs. CMOS version



<u>Success:</u> drop coating of thick sensing layers
more stable than thin metal-oxide films

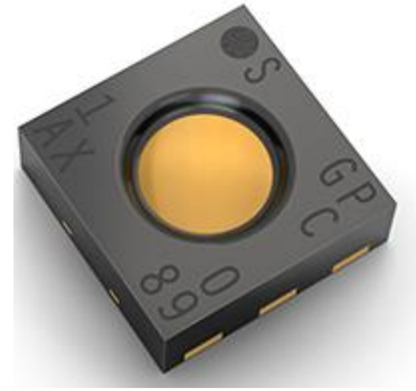


Sold in millions of units for air quality systems (AQS) in cars (CO, NOx…)



M. Graf et al., ETHZ

Dual flat no leads (DFN) package



For IoT: Total VOCs

4 sensors on same hotplate
Inkjet of sensing layers
Size: 2.45 x 2.45 x 0.75 mm
Interface: I^2C
Supply voltage: 1.8V

Sensirion AG (CH)

Sensirion SGP30 for Volatile organic compounds (VOCs)

- **A fully digital gas measurement solution monolithically integrated on one chip**
- **Integration of 4 sensing elements in one sensor**
- **Metal-oxide nanoparticles**
- **Long-term stability through siloxane resistance**

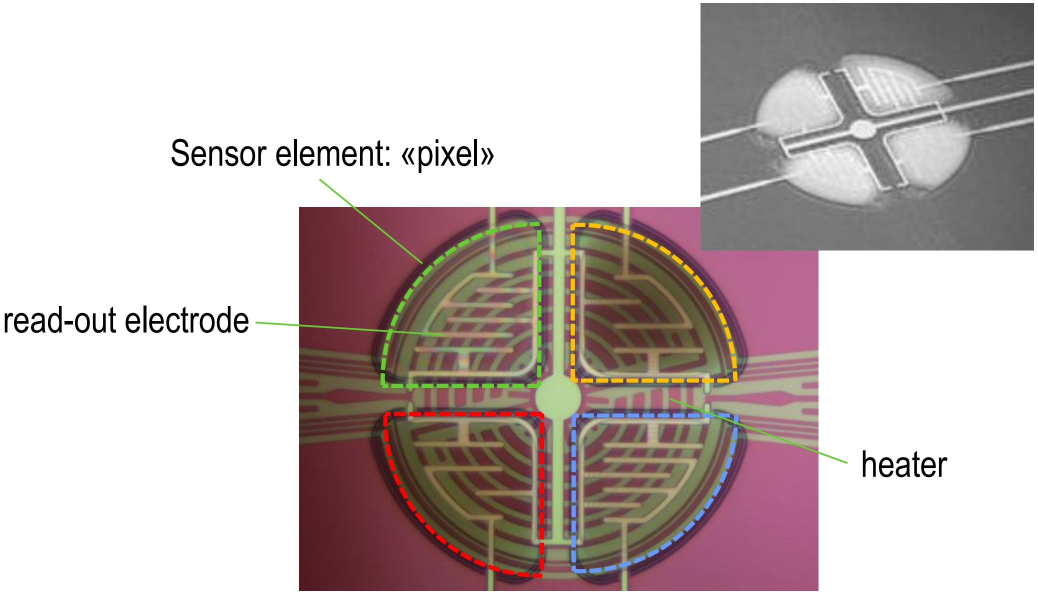


Figure: *Micrograph of the SGP showing the four sensing elements, the read-out electrodes and the heater.*

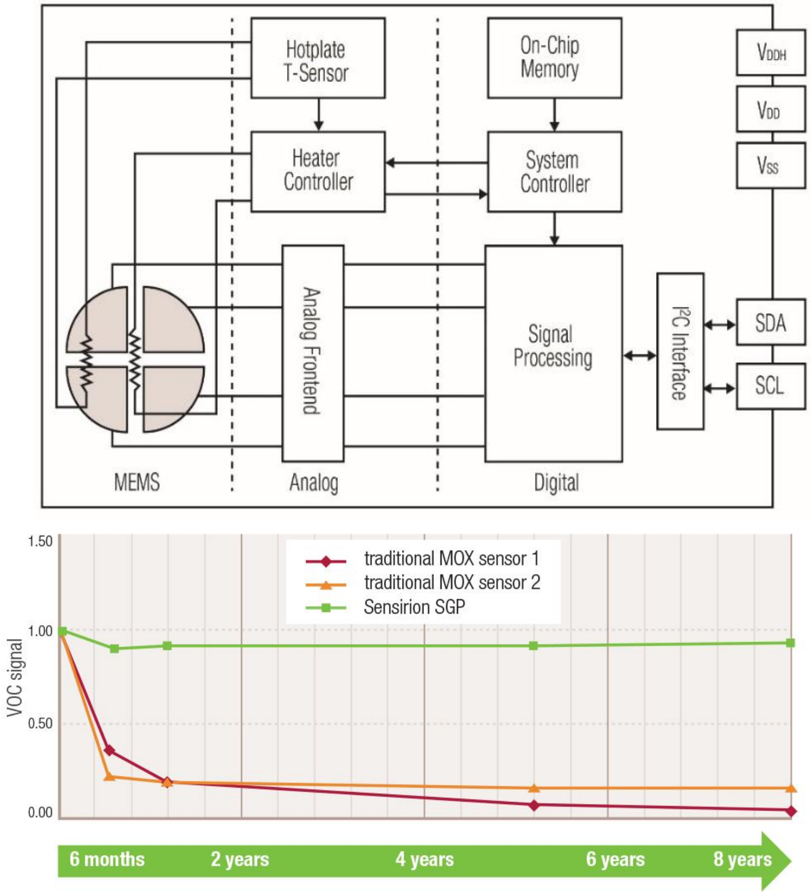
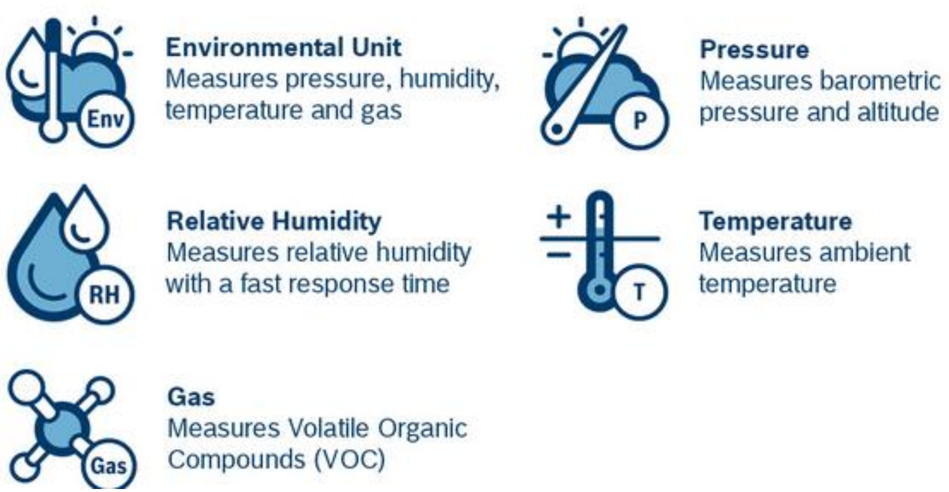


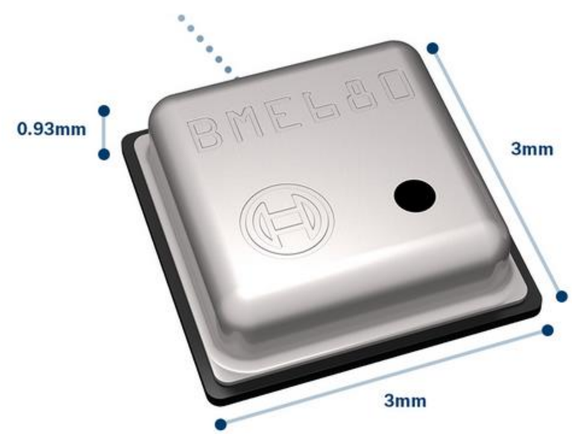
Figure: *Long-term stability of the SGP in an accelerated life-time test. The sensors are operated for 200h in 250 ppm D5 (decamethylcyclopentasiloxane) to simulate 10 years of operation in a typical indoor environment.*

Gas sensors: Chemoresistive metal-oxide (MOS)

Bosch BME 680 integrated environmental sensor

- Developed specifically for mobile applications and wearables where size and low power consumption are key requirements
- Gas, pressure, humidity and temperature sensors
- Volatile Organic Compounds (VOC) from paints (such as formaldehyde), lacquers, paint strippers, cleaning supplies, furnishings, office equipment, glues, adhesives, alcohol
- 8-pin metal-lid 3.0 x 3.0 x 0.93 mm³ LGA package

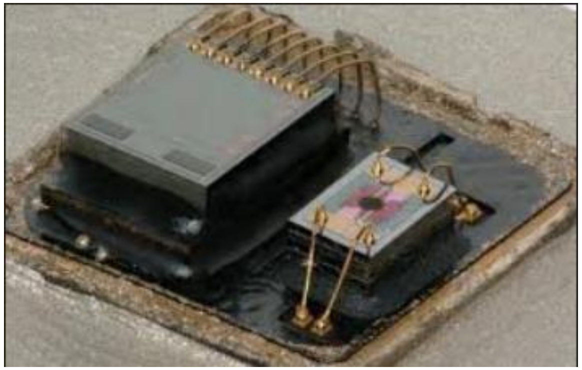




Bosch BME 680 integrated environmental sensor

Applications

- Air quality measurement
- Personalized weather station
- Context awareness, e.g. skin moisture detection, room change detection
- Fitness monitoring / well-being
- Warning regarding dryness or high temperatures
- Measurement of volume and air flow
- Home automation control (e.g. HVAC)
- GPS enhancement (e.g. time-to-first-fix improvement, dead reckoning, slope detection)
- Indoor navigation (change of floor detection, elevator detection)
- Altitude tracking and calories expenditure for sports activities

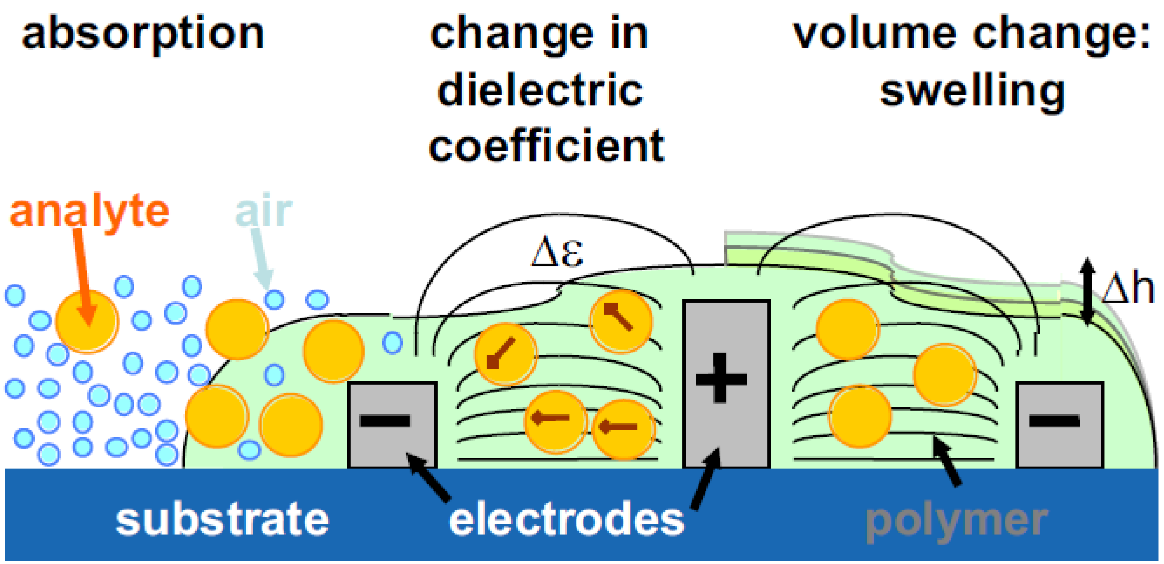


Chemocapacitor

- Chemocapacitors (dielectrometers) rely on changes in dielectric properties of sensing material upon analyte exposure.
- Interdigitated structures analogous to room temperature chemoresistors
- Capacitances measured at AC frequency up to 500 kHz.
- Two effects change capacitance of sensitive layer:
  - swelling and
  - change of dielectric constant due to analyte incorporation

Chemocapacitor with polymeric sensing layer

- Used for humidity sensor
- VOCs can be also detected but very often signal much smaller than the one from humidity



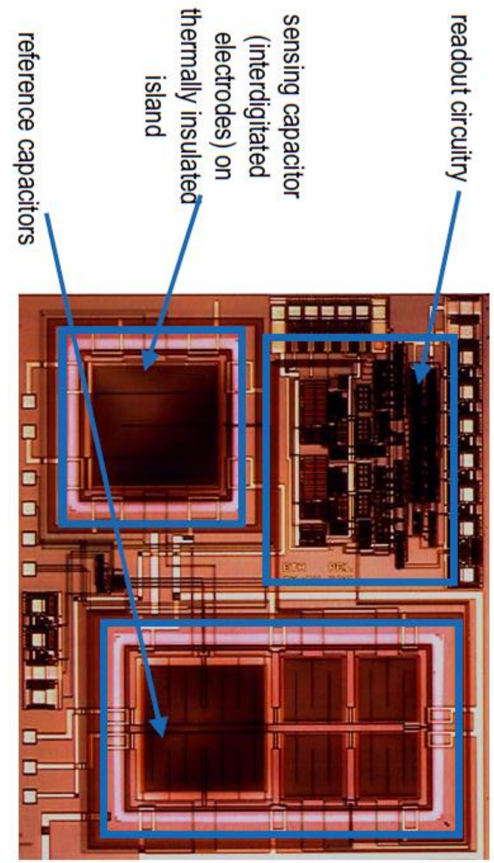
ε polymer: 3-4

ε humidity, water: 81

$$C = \varepsilon_0 \varepsilon_r\, A/d$$

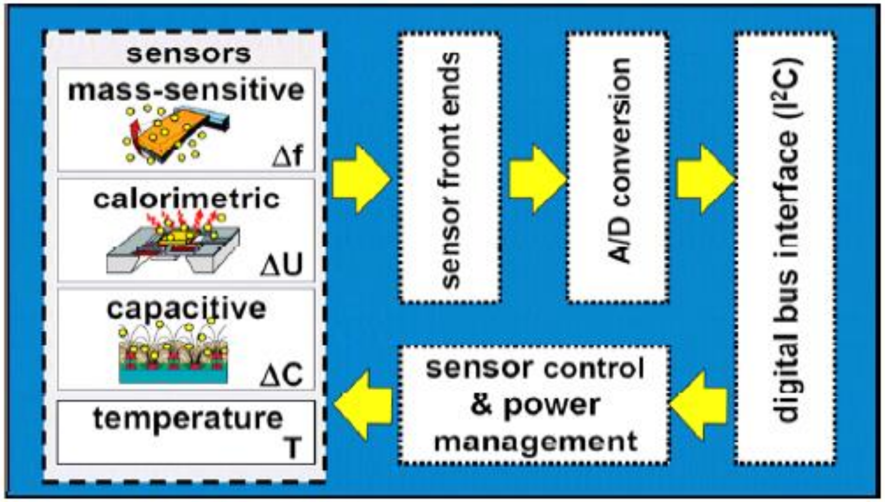
CMOS digital humidity and temperature sensor

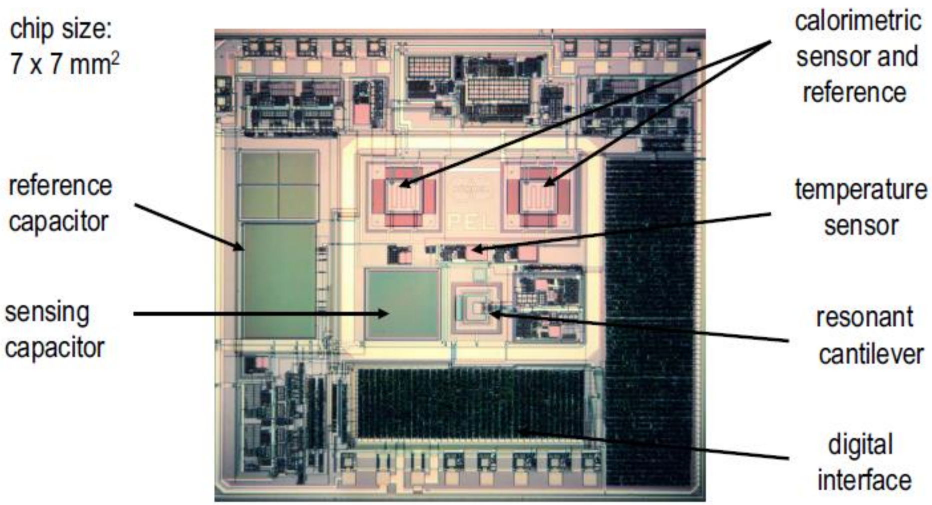
- Capacitive sensor element
  ⇨ 0...100%RH measurement range
- Calibrated and digital output
  ⇨ identical output of all sensors
  ⇨ easy integration with customer's µC
- Fully AEC-Q100 qualified
  ⇨ Excellent long-term stability
- Fast response time (8sec 1/e)
- Low power consumption (no self heating)
- Small size



Gas sensors: CMOS multi-sensor

- Multiple sensors system for discriminating different gases in a mixture
- Same or different types of sensor technologies
- CMOS integration was demonstrated with digital output signals



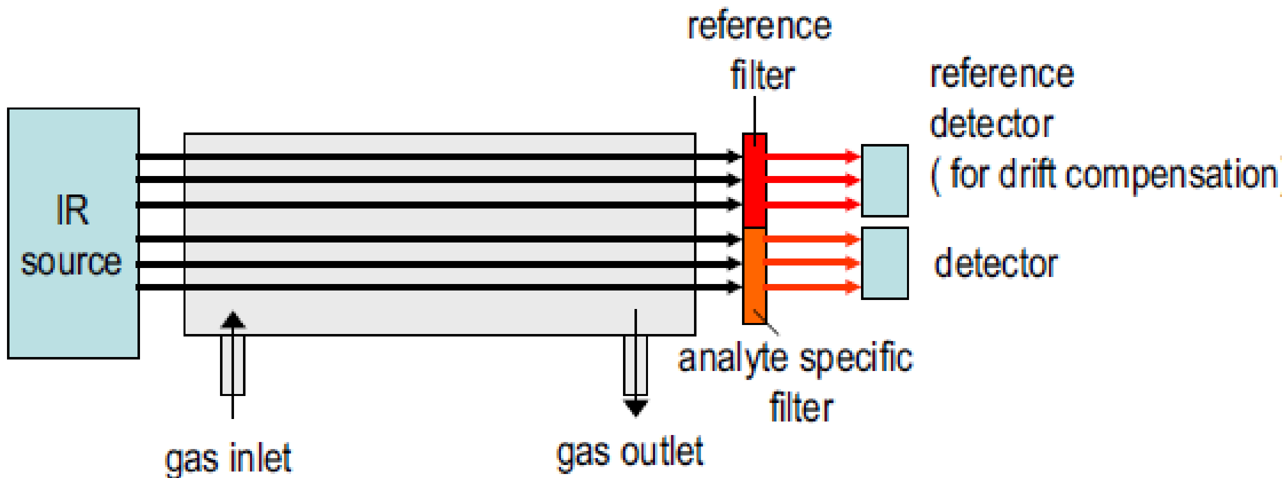


A. Hierlemann, ETHZ

Non dispersive infrared (NDIR) gas sensor

<u>Molecules have an unique absorption spectrum in the infrared</u>

- IR gas sensors provide better selectivity
- Gases are not in touch with the detector

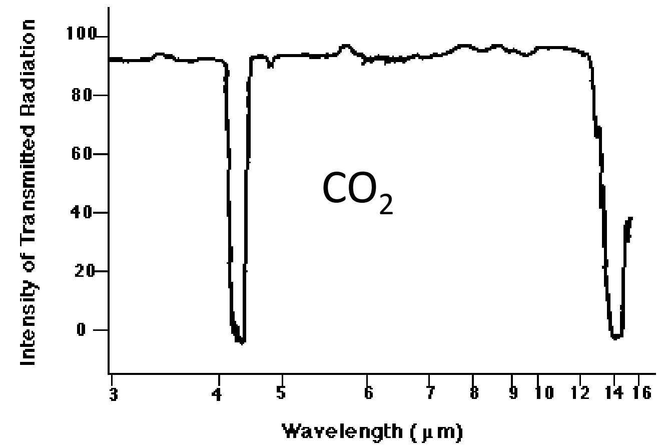


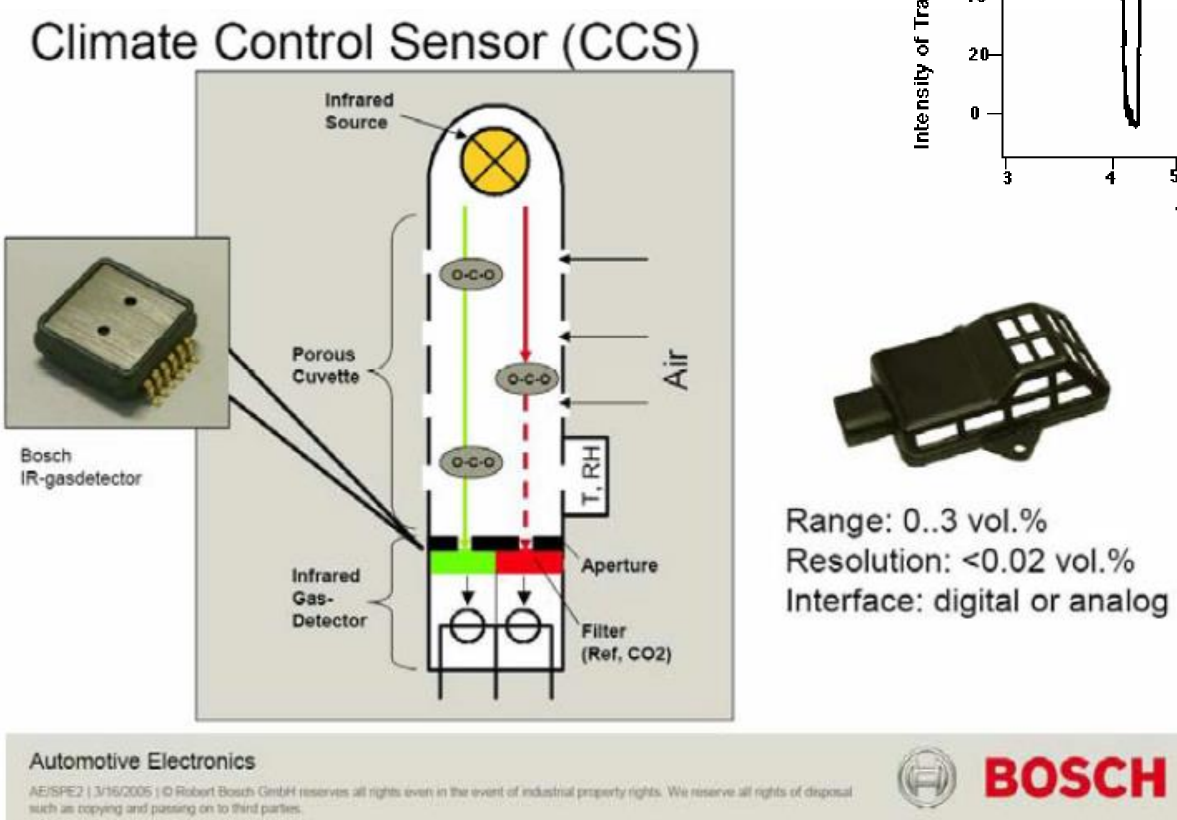
$$I = I_0 \cdot e^{-k \cdot l \cdot c}$$

Lambert-Beer Equation

I: light intensity at detector
I_0: incident light intensity
k: extinction coefficient
l: length of absorption
c: analyte concentration

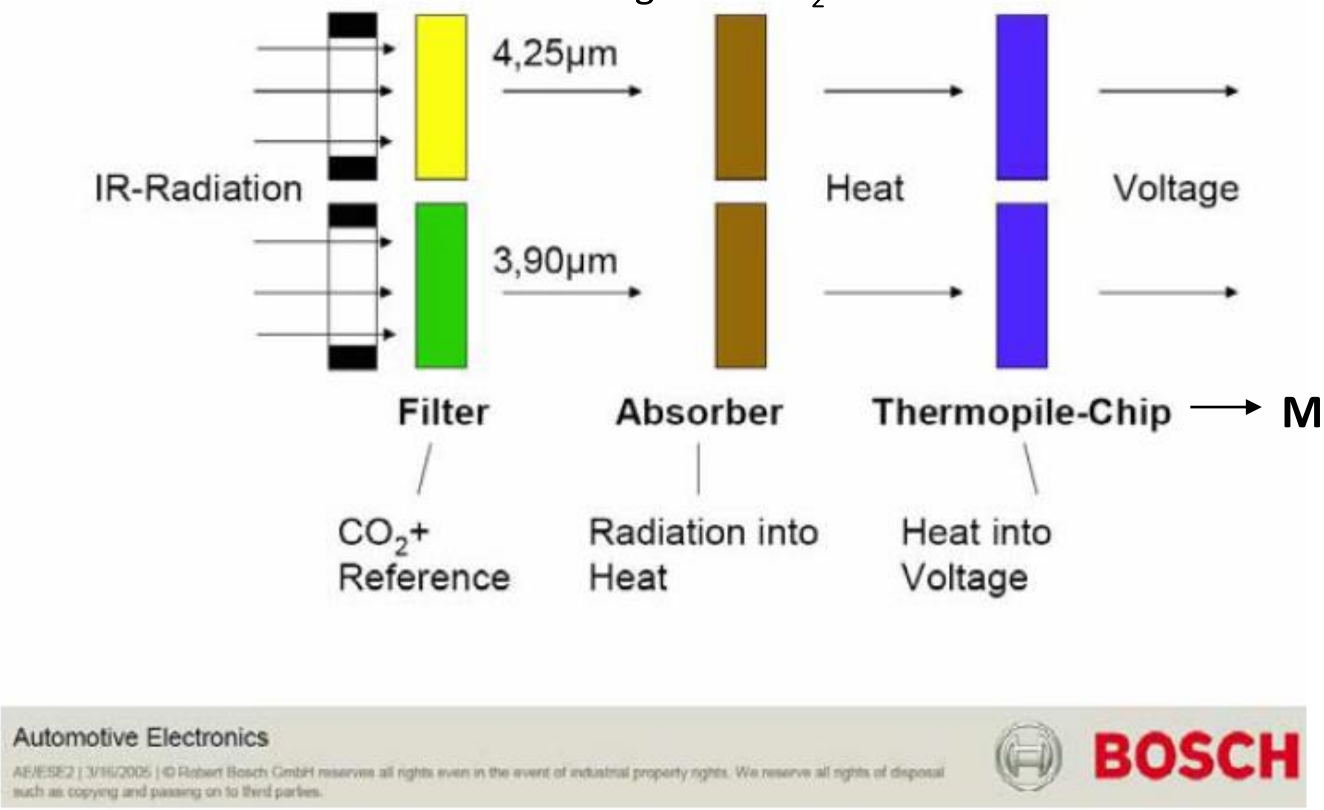
Non dispersive infrared (NDIR) gas sensor





Non dispersive infrared (NDIR) gas sensor

Wavelength for CO_2 detection

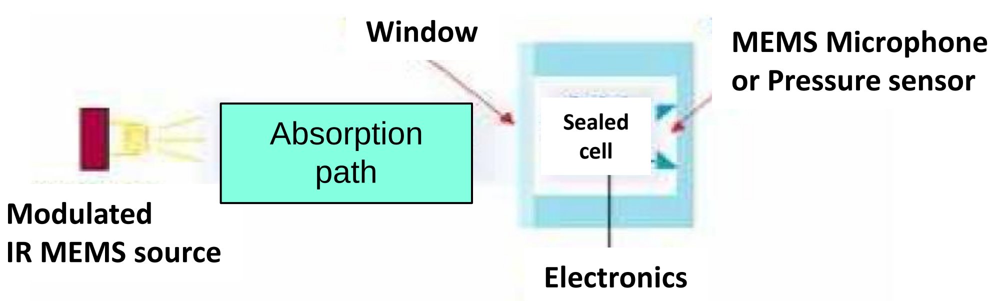


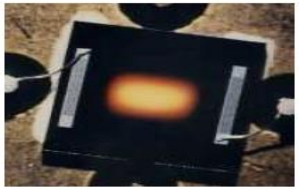
→ **MEMS chip**

Photoacoustic (PA)

Conversion of absorbed light energy into acoustical waves

- Absorption path: gas in the ambient environment
- Sealed cell: cell with the gas to be detected (ex. CO_2)
- Intensity of light reaching the sealed cell will have an influence on the amplitude of the acoustical waves generated and therefore on the sensor signal



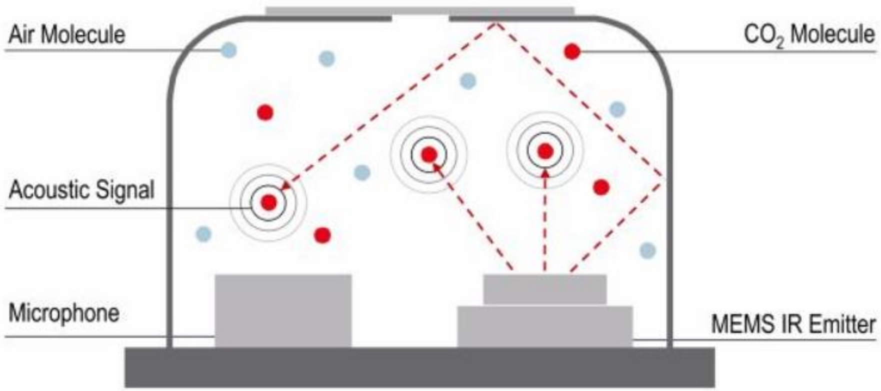


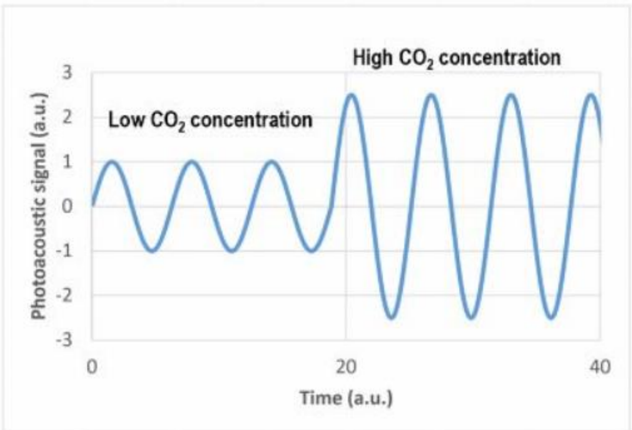
- Refrigerant gases
- Carbon dioxide

SINTEF Electronics and Cybernetics

Photoacoustic (PA)

CO_2 - Photoacoustic sensing technology





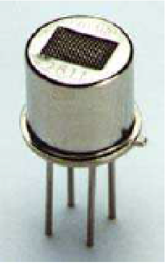
Confidential

SENSIRION
THE SENSOR COMPANY

Micro gas sensors: Status and perspectives

Status

- Transducers: miniaturized
- Gas sensitive materials: tons of them
- Electronics: separated chips (ASICS)
- Packaging: the famous TO header



Perspectives

- Transducers: micro- nano- machined
- Gas sensitive materials: nano- bio- materials
- Electronics: on chip, bio inspired data process
- Packaging: higher integration, wafer level

Questions

- Micro-hotplates
  - Design, fabrication, thermal characterisation techniques
  - How to minimise heat losses
  - What factors can influence temperature distribution on heating area
  - Simulations: physical parameters important for simulation
  - How to realize IR emitter: hotplate implementation + packaging
  - Reliability
  - Applications to physical and gas sensors: type of sensors, implementation, advantages

- Gas sensors
  - Components of a gas sensor, gas sensor vs. gas sensing system
  - Principles of operation of the different types of transducers
  - Gas sensors important characteristics (5S), gas sensor response, response and recovery time
  - Which sensor(s) to use for sensitivity, selectivity, to detect specific gases (H_2, CO_2, reducing, oxidising gases, VOCs, methane, etc)
  - Sensing principles with lower-power consumption
  - CMOS gas sensors: which types of sensors, advantages, multi-sensor