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Application of MEMS CMOS Broadband Infrared Emitters and Detectors for Compact NDIR CO_2 Censing

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Function in the Action: (WG Member)

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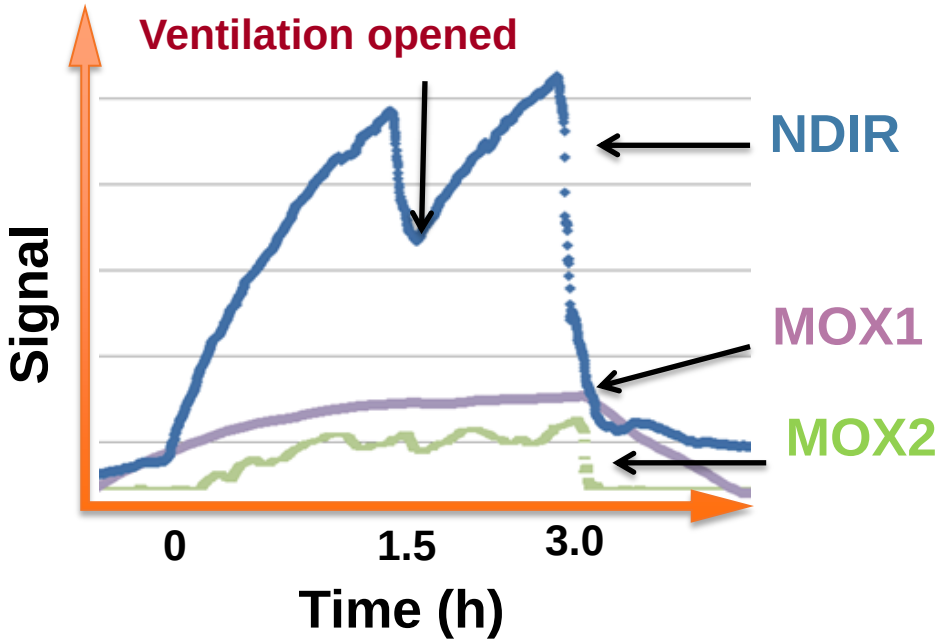
Need for Compact CO_2 Sensor

- Environment
- Indoor Air Quality
- Process control
- Medical diagnosis
- Internet of Things

State-of-the-art solutions

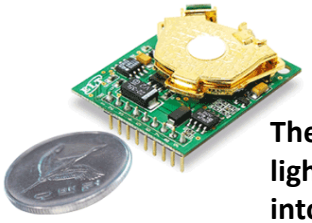
- Metal Oxide
- Thermal conductivity
- NDIR



Heating voltage (V_H)	3.0 DC
Heating current (mA)	Approximately100
Response time (90%)	10s
Recovery time (90%)	30s
Dimensions (mm)	10 × 14 × 18mm

Some Compact NDIR CO_2 Sensors

For HVAC applications



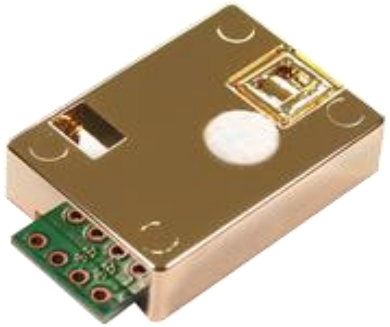
H-550 Sensor Module

IR Gas Sensors

The H-550 CO2 sensor module is the world's smallest and lightest NDIR CO2 sensor module and can be widely installed into the home network, ventilation, controllers, wall-pads, robots, cars and many other devices to control air quality.

TCC ELT
Environment Leading Technology

www.tccelt.co.kr



E+E ELEKTRONIK
YOUR PARTNER IN SENSOR TECHNOLOGY

The digital interface of the CO2 sensor module and the minimal-sized design permit very easy integration into devices, e.g. for demand controlled ventilation or data loggers.

T-100 is the claimed to be world smallest CO2 sensor module

SprintIR™

GSS
GAS SENSING SOLUTIONS

High Speed Carbon Dioxide Sensor

SprintIR is a high speed (20 Hz) CO_2 sensor, ideally suited for applications which require capture of rapidly changing CO2 concentrations including metabolic assessment and analytical instrumentation.

- High speed sensing (20Hz)
- Measurement ranges from 0 to 100%
- 3.3V supply
- Low power requirement 35mW
- Flow through adaptor now available

SprintIR™ Sensor

The world´s smallest NDIR CO_2 sensor

SenseAir presents the world's smallest CO_2 sensor, *SenseAir® S8*, which despite its small size has the same excellent performance as SenseAir's other sensors.

SenseAir®

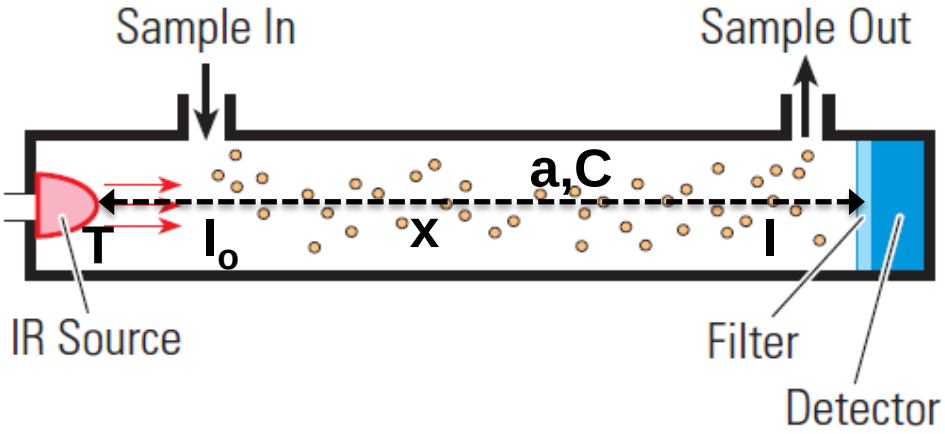
Problems with Current Solutions

- Metal Oxide/Thermal conductivity:
  - Indirect measurement – Correlation between VOC
  - Selectivity
  - Stability
  - Reliability
  - Low cost

- NDIR
  - Direct measurement
  - Complex
  - Bulky
  - Relatively expensive
  - But most reliable method of measuring CO_2

Non-Dispersive Infrared (NDIR) based on Beers Law

$$T = I/Io = e^{(-axC)}$$



where:

T = Transmittance of light through the gas to the detector

I = light intensity after absorption by CO_2

Io = light intensity at zero CO_2 concentration

a = specific CO_2 molar absorption coefficient

x = path length

C = CO_2 concentration

How compact NDIR CO_2 be made?

$I/Io = e^{(-axC)}$ **Rearranging this equation:**

$\ln(I/Io) = axC$ **Rearranging this equation:**

$$C = (\ln(I/Io))/(a*x) \text{ or } x = (\ln(I/Io))/(a*C)$$

I and Io - are measured by detector (SNR of the instruments readout)

a - is a constant CO_2 molar absorption coefficient at a wavelength of 4.26 µm

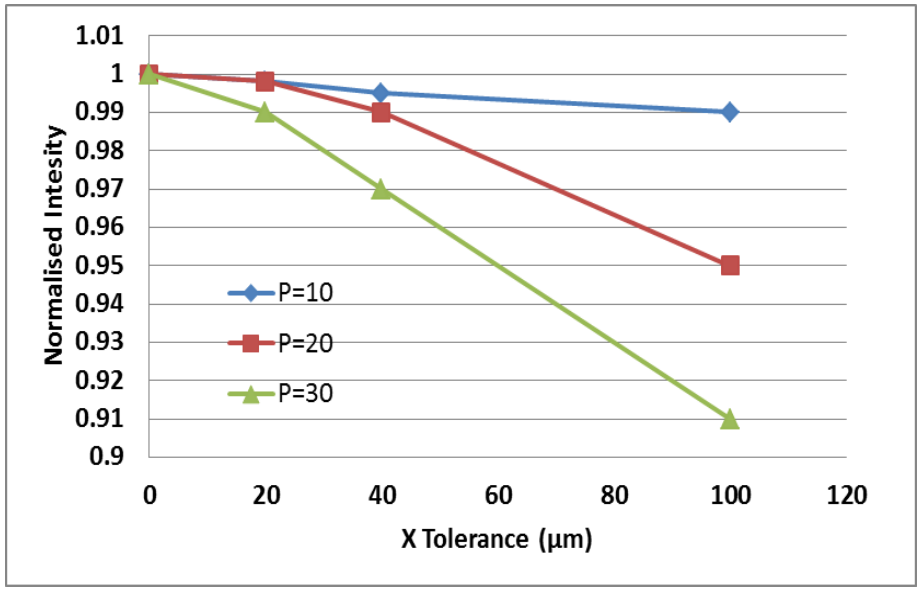
x - path length of the detection cell
– essentially higher the C shorter the path length

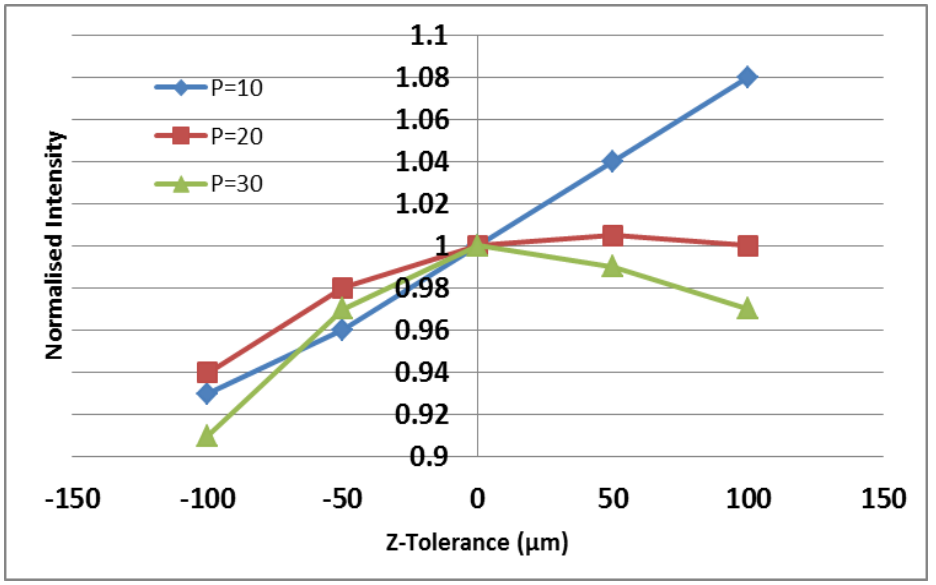
It can be shown that for:
5000ppm minimum x needed is at lease 30mm (Environment)
50000ppm x can be < 10mm (Breath analysis)

Components used in NDIR

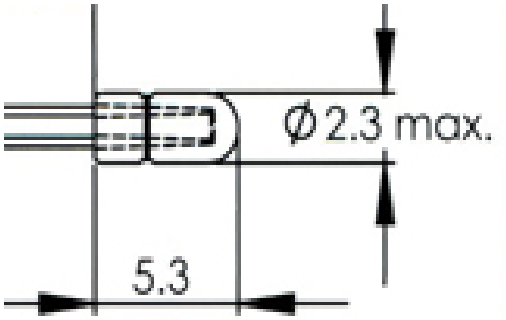
- Micro-bulb
- Thermopile or Pyro detector
- Optical filter
- Optical Path with reflectors
- Electronics

Issue of Optical Alignment

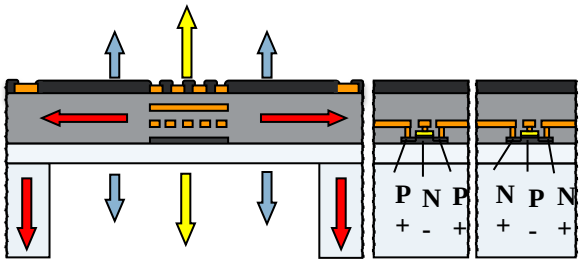




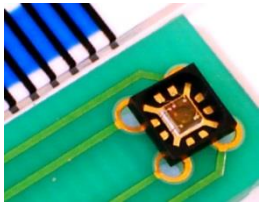
Parabolic reflector X/Y/Z alignment



Micro-bulb – large tolerance

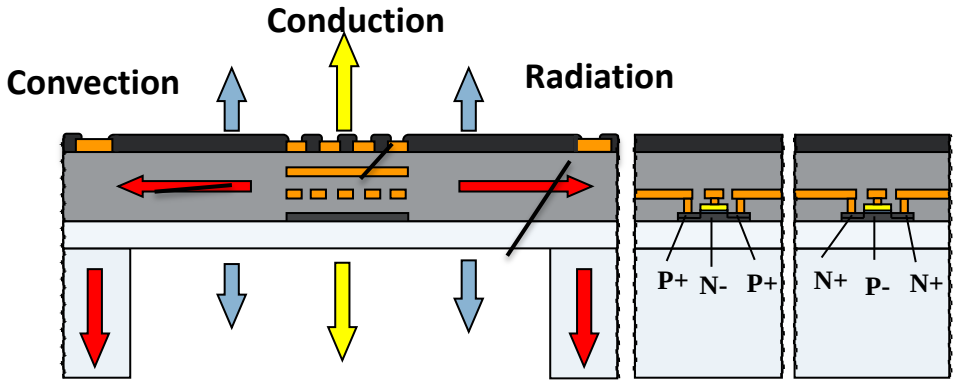


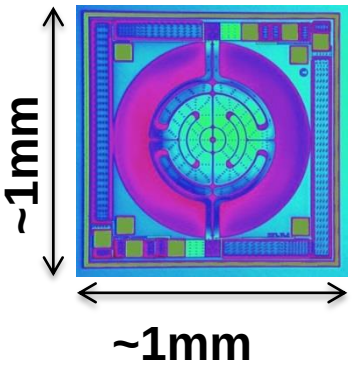
MEMS IR Emitter/Detector
1mm x 1mm die

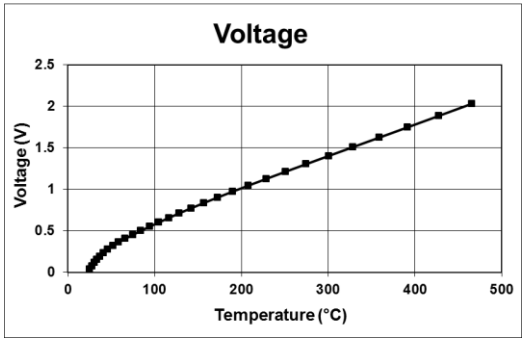


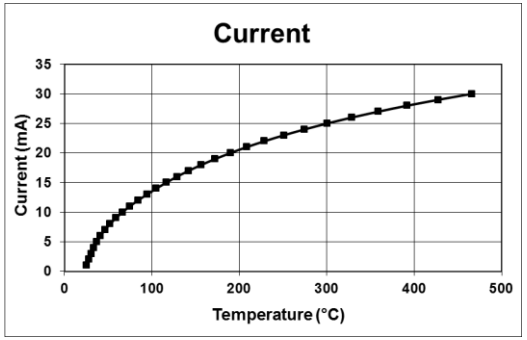
Example of packaged
MEMS IR Emitter/Detector

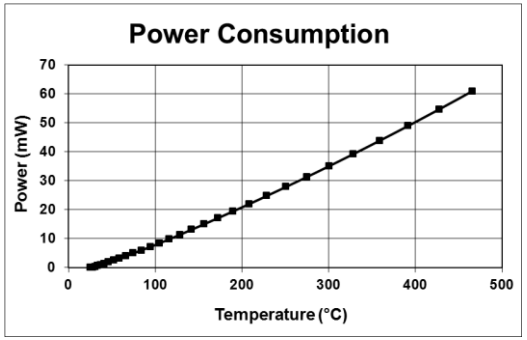
MEMS IR Emitter





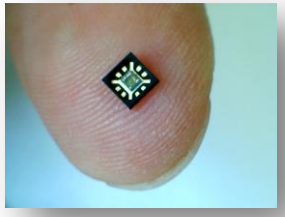




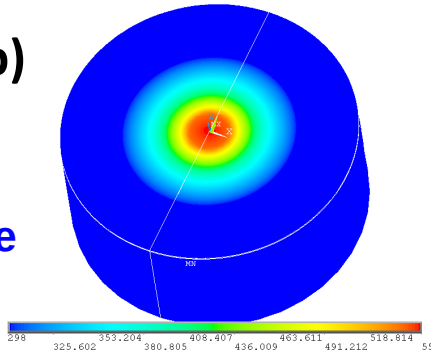


Emitter is capable of:

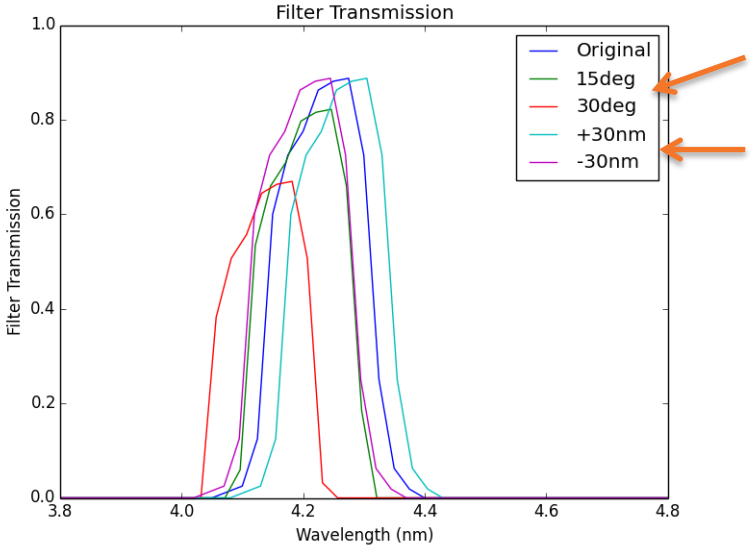
- **High Temperature (>500°C), High stability (< 1%)**
- **High reproducibility (99% Yield)**
- **High reliability (>5 years)**
- **Miniature device 1mm x 1mm die**
- **< 30ms transient**
- **Fast switching (> 20Hz vs 5Hz(micro-bulb)**



Point source

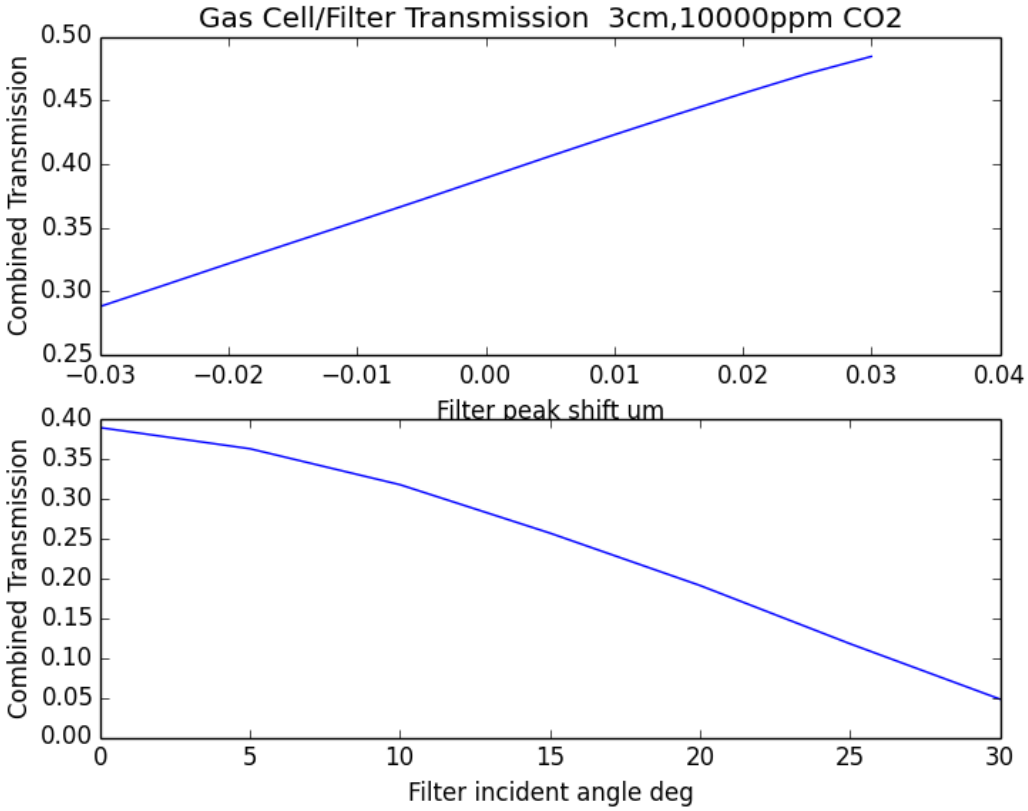


Optical Filter Issues



Ray Incident angle

Peak wavelength



Filter transmission characteristic depends on:

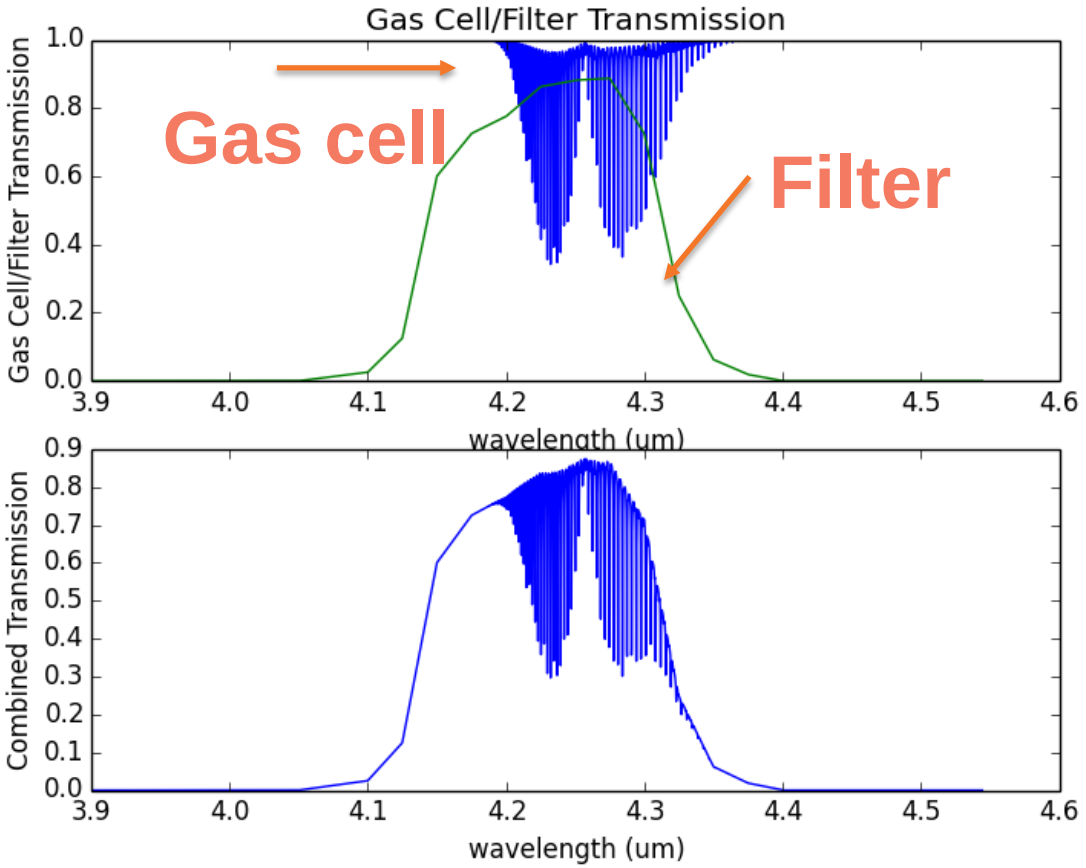
- **Ray incident angle**
- **Filter temperature**

There is also some tolerance on:

- **Peak wavelength**
- **Bandpass width**

Any design should account for worse case.

Spectral absorption profiles



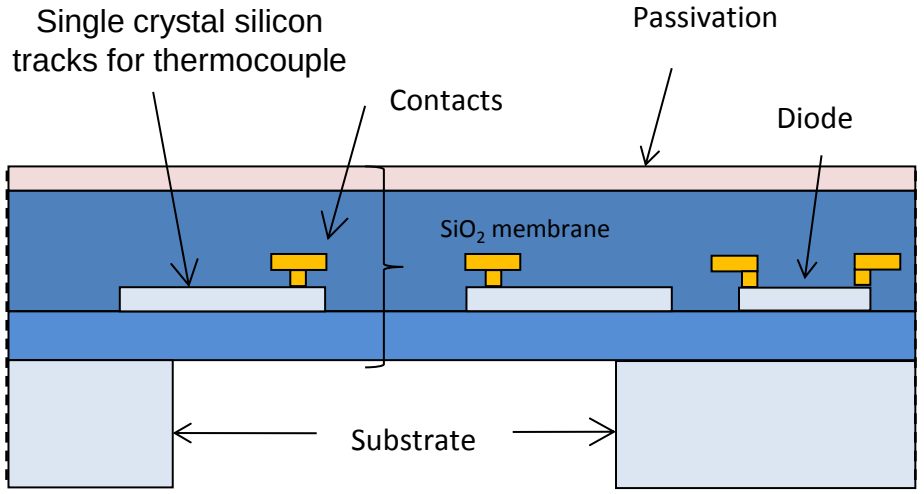
4.26µm CO_2 Absorption Peak

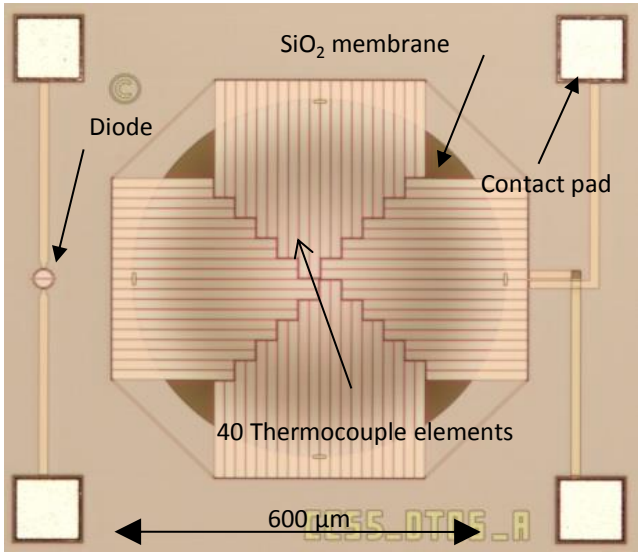
4.2-4.35nm band

Combining filter peak shift, incident angle and temperature can have significant impact on output signal, hence noise!

MEMS IR Detector

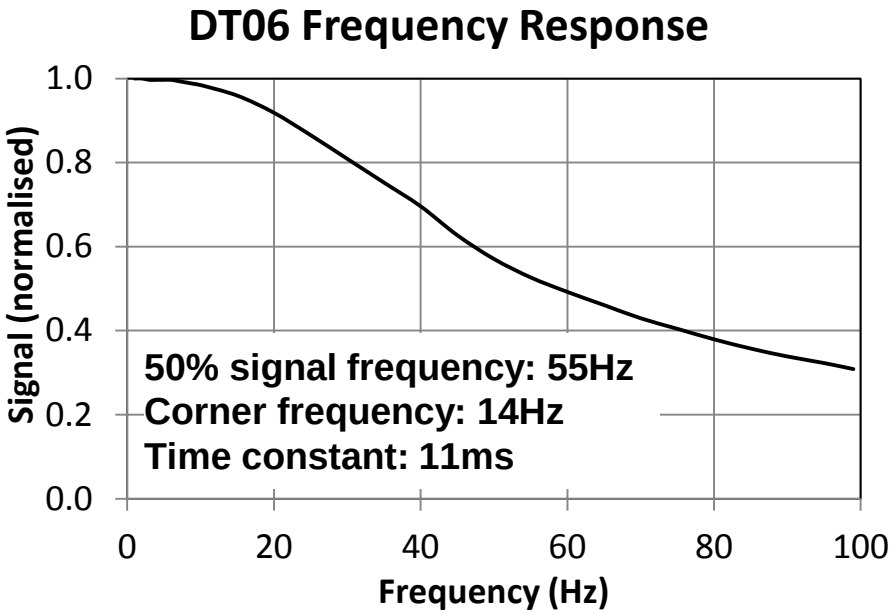
Design: Single crystal silicon p+ and n+ elements with Tungsten interconnects. SiO_2 membrane of high thermal resistance to enhance the IR heating of the thermopile

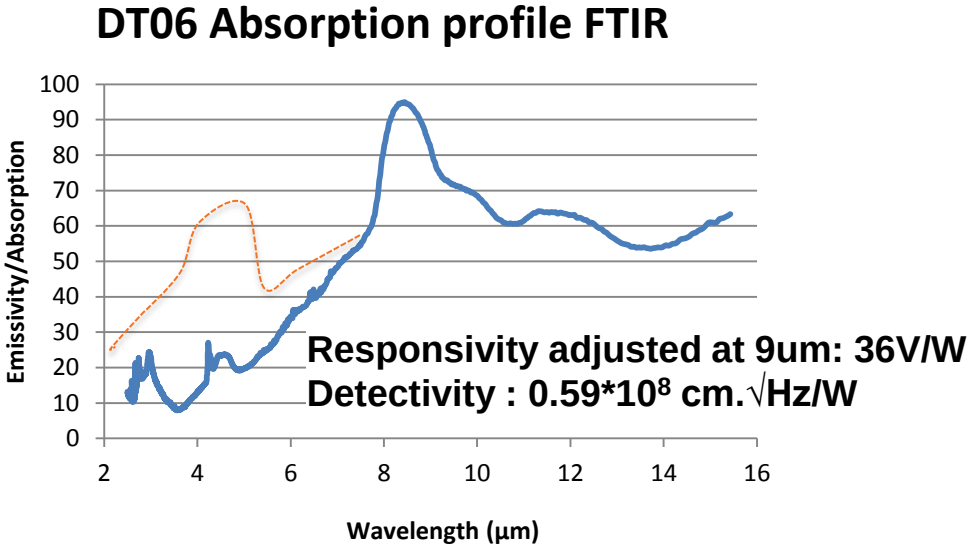


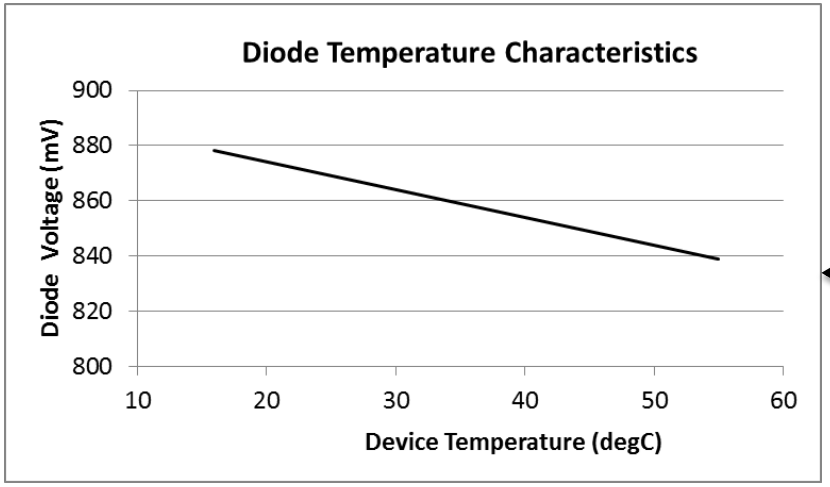


1.16mm x 1.06mm chip, Sensing area $0.3mm^2$

MEMS IR Detector: Key Parameters



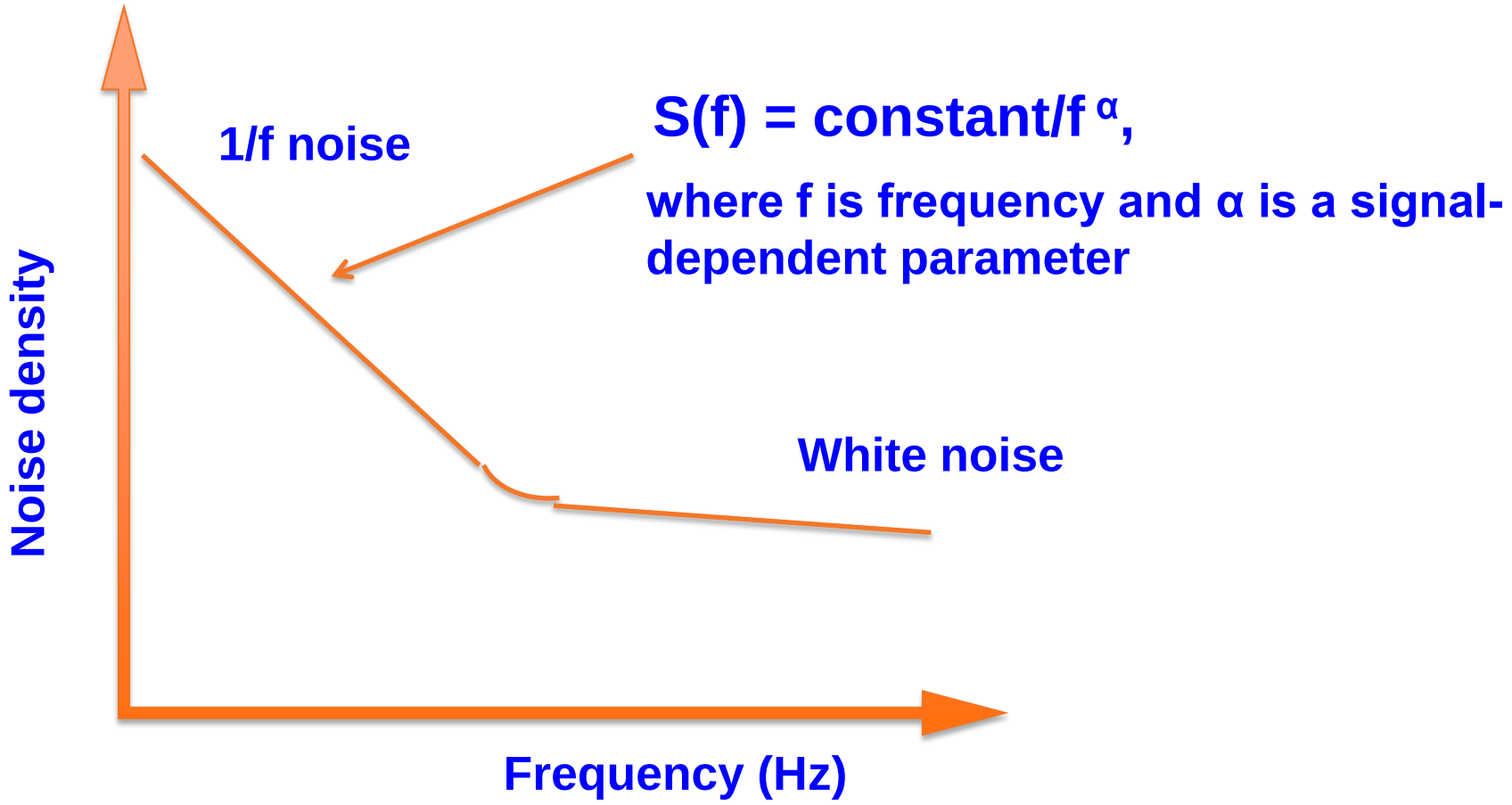




Improved spectral performance at lower wavelength (IR Emitter/Detectors)

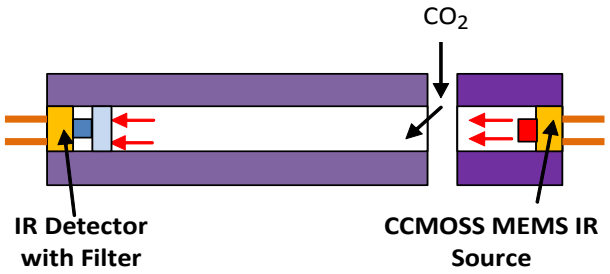
Diode Voltage: (Typ.) 869mV at 65µA
Diode Temperature coefficient: (Typ.) -1.004mV/C
Linearity R^2>0.9997

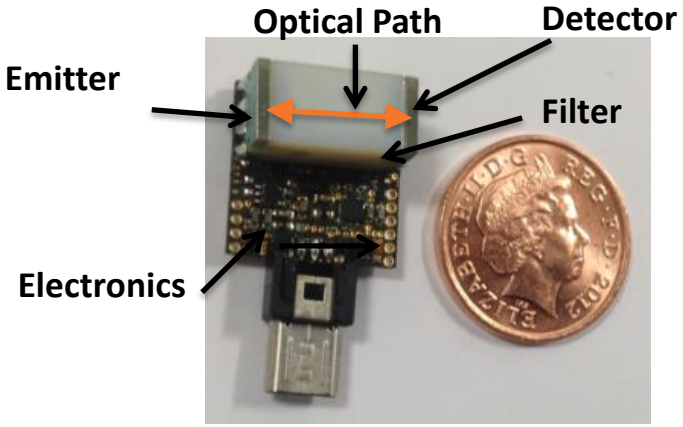
Noise Optimisation



Combining fast MEMS IR Emitter and Detector not only mechanical chopper can be eliminated but also noise performance can be optimised

Construction of Compact NDIR Sensor

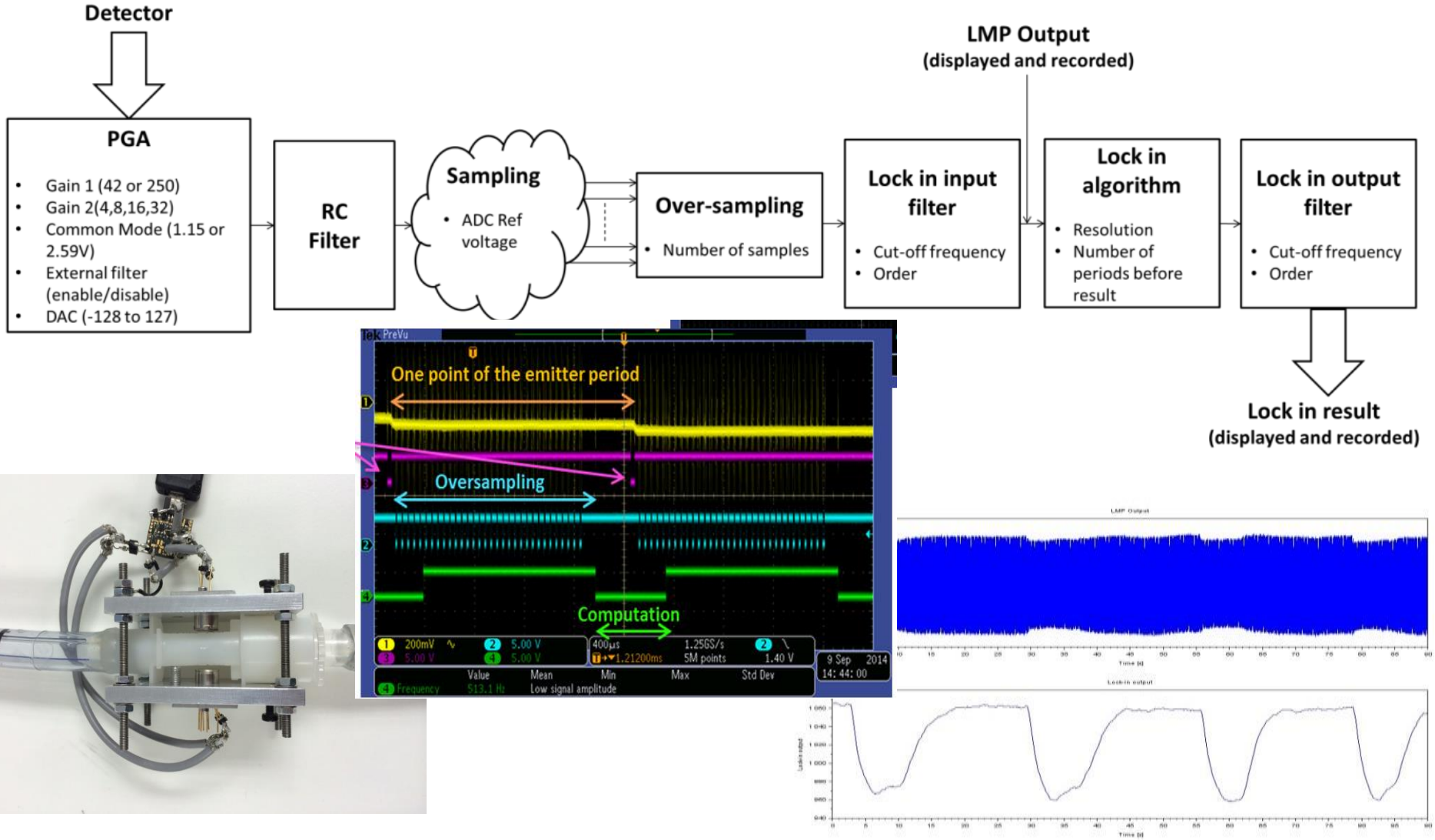




With micro-bulb and TO packaged IR Emitters and detectors a compact solution cannot be achieved!

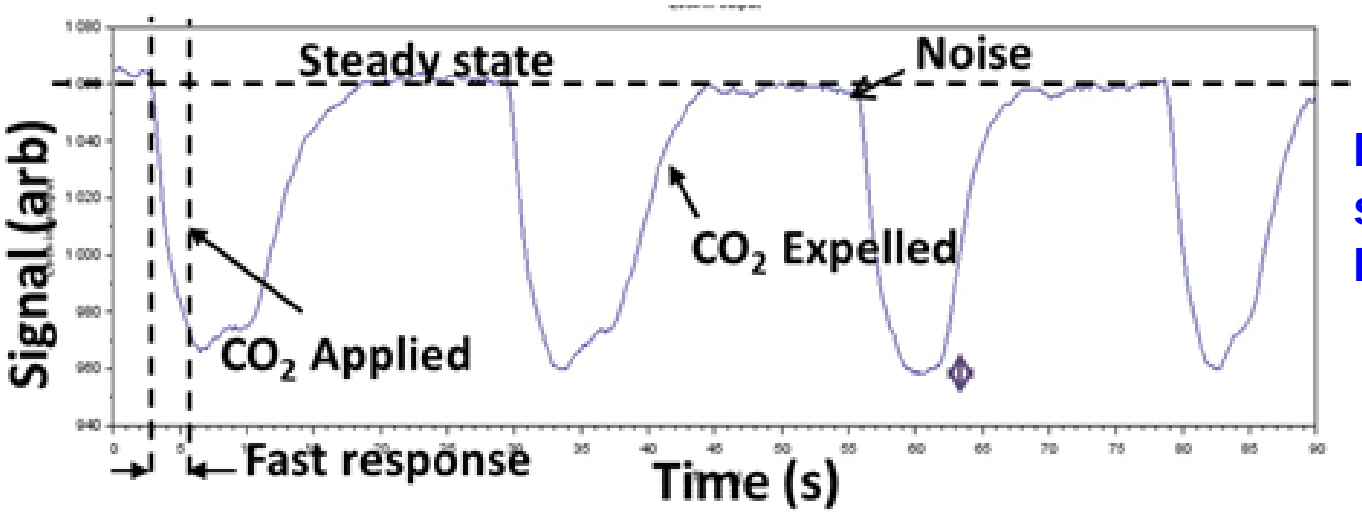
Best option is MEMS solution

NDIR System Electronics

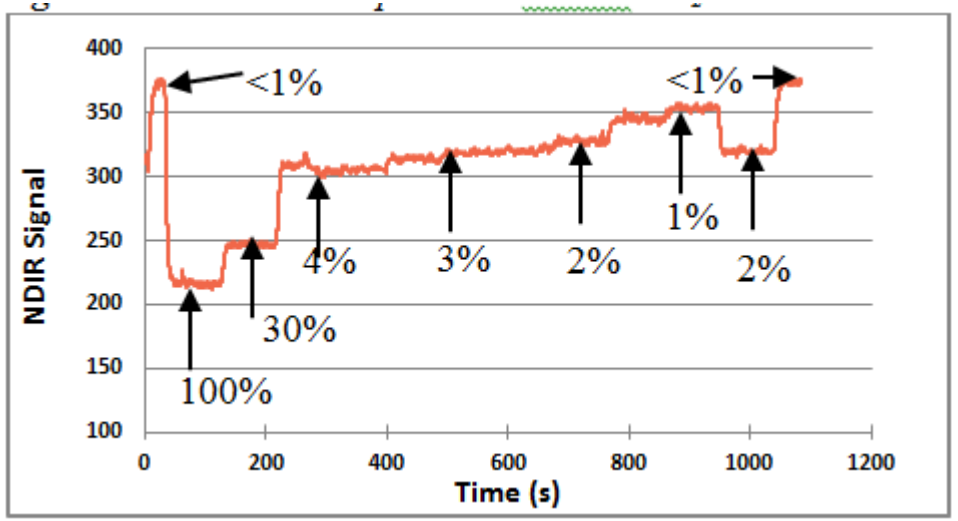


Demo for high concentration real-time breath CO_2 measurement

Initial Measurements – Worst case Example

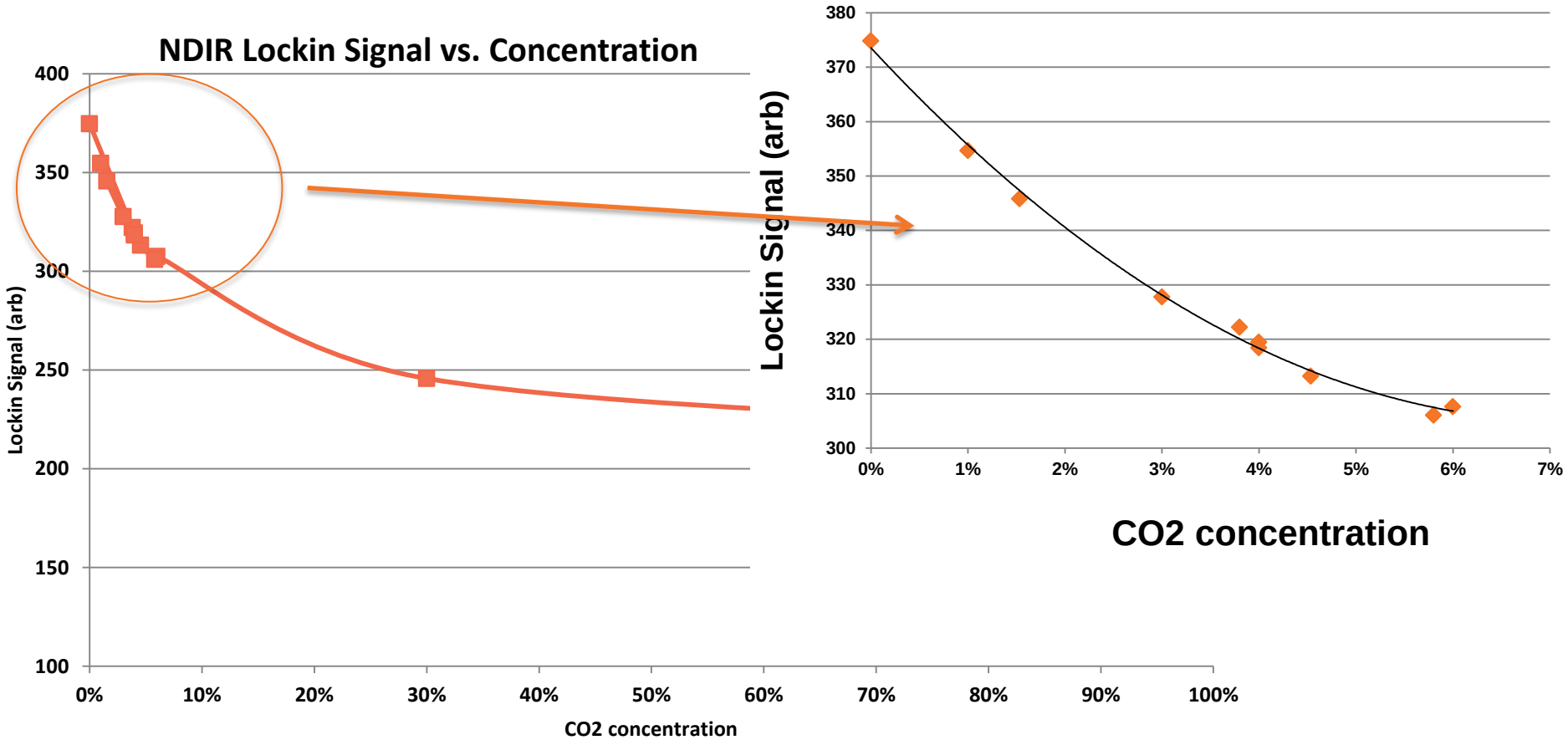


Exhaled breath blown in a sample chamber and Expelled using a pump

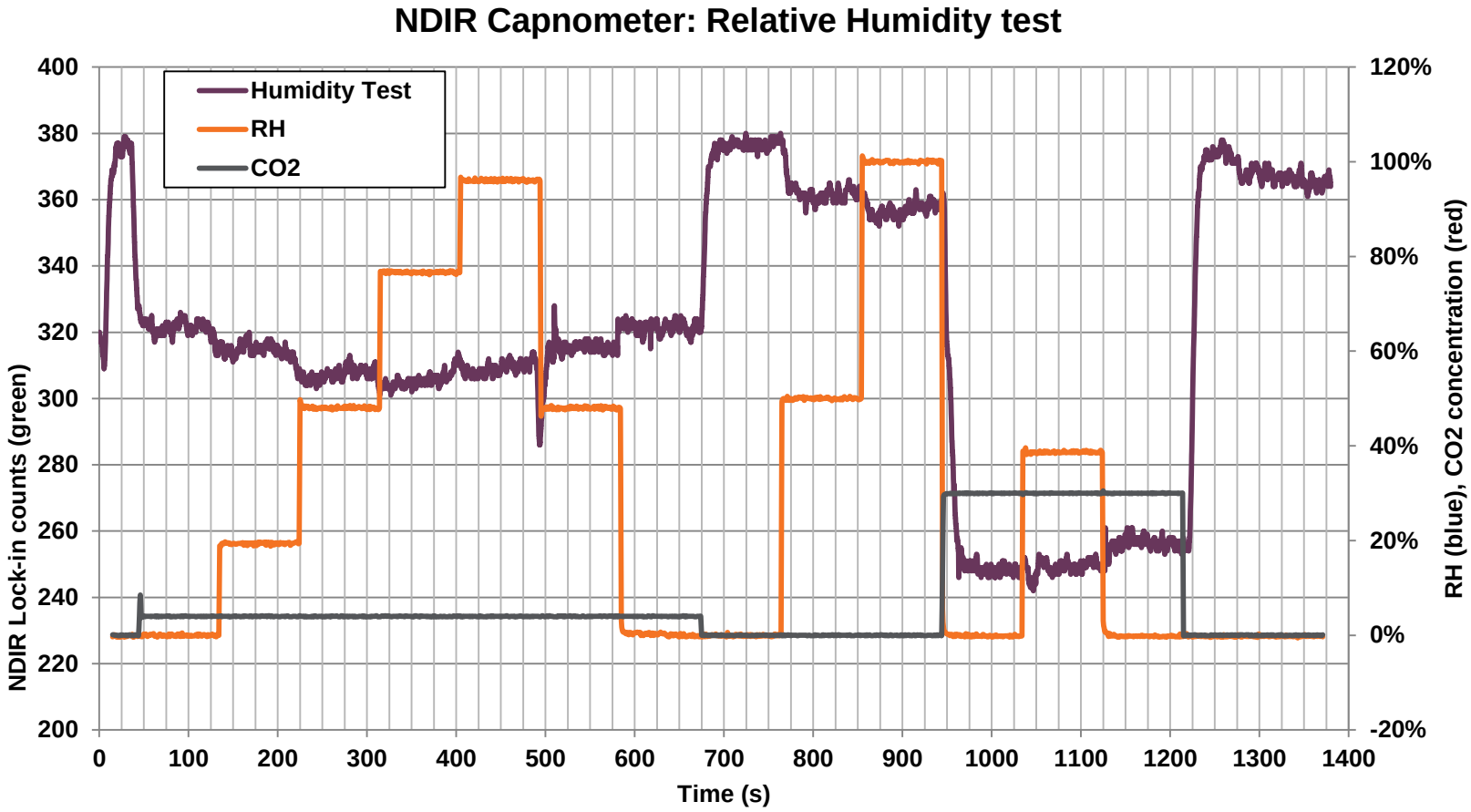


Measured in gas test chamber using MFC

CO_2 Sensitivity measurement: Worst Case Example



Effects of Humidity



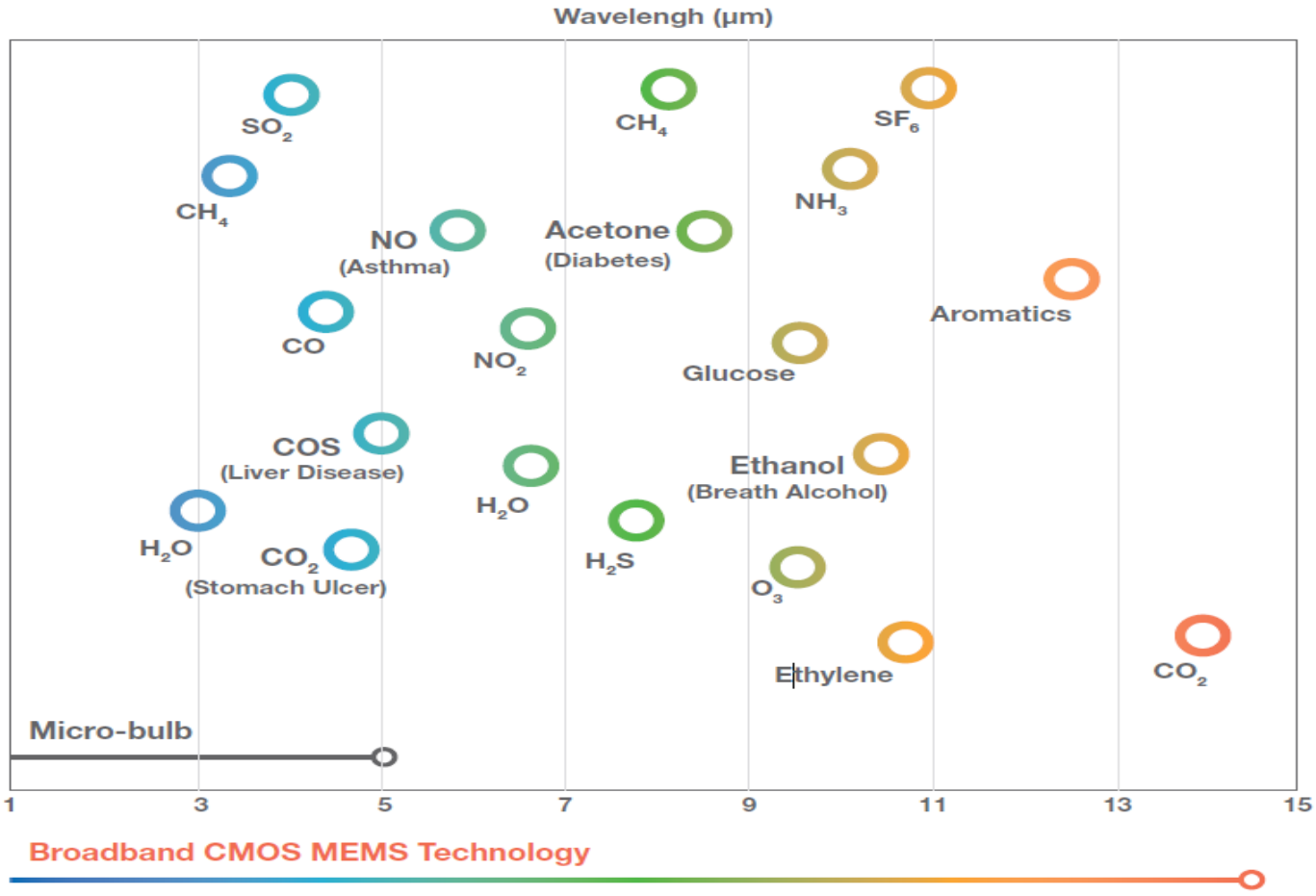
Thus built-in compensation circuits on CMOS platform will lead to more compact solutions

Examples of Commercial CO2 Breath Analyser(Capnometer)

- Masimo EMMA
- Viamed VM-2500-M
- Philips Respironics TIDAL WAVE
- UtechMedical UT100C

Typical cost > $1K, so low cost high volume solutions would greatly benefit in saving lives or improve quality of life!

Mid-IR Applications



Depending on the gas concentration level (ppm/ppb) to be measured MEMS IR Emitters and Detectors can be exploited for sensing other interesting gases

MOX Sensor Products

CAMBRIDGE CMOS SENSORS

Overview

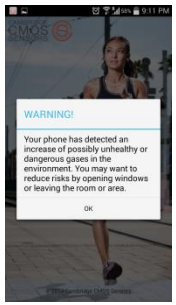
- Common foot-print SMD
- Serve multiple purposes and wide range of applications

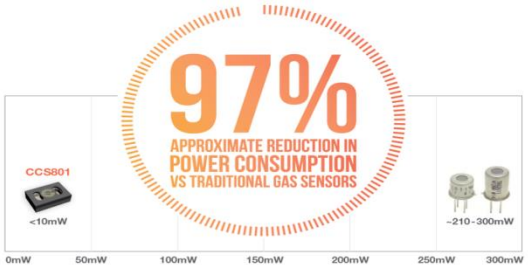
Requirements

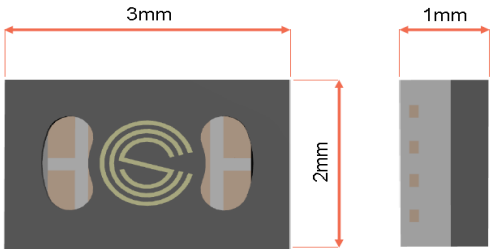
- Ease of integration
- Small size
- Ultra low power
- Low cost
- High volume

Solution

- Worlds smallest and lowest power gas sensor
- Supports IAQ / CO monitoring & alcohol breath analysis
- Fast response
- Sensor array for multi-gas sensing and redundancy
- Scope for further miniaturisation







CONCLUSIONS

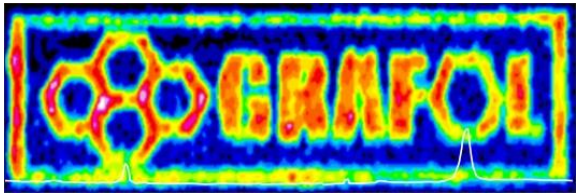
- *MEMS IR Emitters and Detectors are true enabler for low cost and high volume NDIR gas sensors.*

- *Signal to noise ratio (SNR) can optimised with the benefit for higher switching frequency offered by MEMS IR Emitter and Detector solutions when compared with micro-bulb.*

- *Using MEMS and SMD or Die-PCB solution, can enable future compact NDIR solutions, not just for AQM, Medical but also IoT.*

Current EU Projects activities

- SOIHITS (Harsh Environment)
- MSP (3D TSV Packaging)
- GRAFOL (Advanced Material)
- E2SWITCH (Ultra-low voltage)



Acknowledgements

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EuNetAir
COST Action

UNIVERSITY OF CAMBRIDGE

THE UNIVERSITY OF WARWICK

SEVENTH FRAMEWORK PROGRAMME

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