

European Network on New Sensing Technologies for Air Pollution Control and Environmental Sustainability - TD1105

INTERNATIONAL WG1-*EuNetAir* COST Action WG4 MEETING on

New Sensing Technologies and Modelling for Air-Pollution Monitoring
Institute for Environment and Development - IDAD
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CMOS SENSOR SYSTEM FOR AIR QUALITY MONITORING



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Function in the Action: (WG Member)

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- Five most disruptive innovations
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- Platform technology
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Five most disruptive Innovations

(according to Forbes @ CES 2014)

1. Embedded sensors:

- Smartphone revolution.
- Low-cost microelectromechanical systems (MEMS), for the Internet of Things.
- MEMS technology expected to be so cheap that it will be cost-effective to add to almost everything!

2. Wearables:

- Revolutionize the massive healthcare sector.
- MEMS revolution has translated to wearables.
- Pulse, blood pressure, sleep, weight and even glucose levels.

3. Exponential Energy:

- Solar power and improved storage batteries for charging other devices
- Hydrogen cell fuel – sensor
- Energy harvesting

4. Driverless vehicles:

- Increased demand for sensors

5. Immersive Interfaces:

- Virtual reality gaming goggles
- Gesture recognition and other sensors



This Includes
Sensors for
AQM

Scientific context and objectives

- Integrated physical sensors, such as MEMS accelerometers, gyroscopes, microphones, are well-established in these portable devices
- Most of these MEMS sensors are CMOS based
- They are typically interfaced via a sensor hub; with most common method of data transfer achieved using I²C communication protocol
- This means any AQM sensors that are incorporated for such application must have similar unified system architecture
- *This will lead to low cost, high volume solutions*
- *Consequently AQM sensors must also be CMOS-based system to make rapid impact*

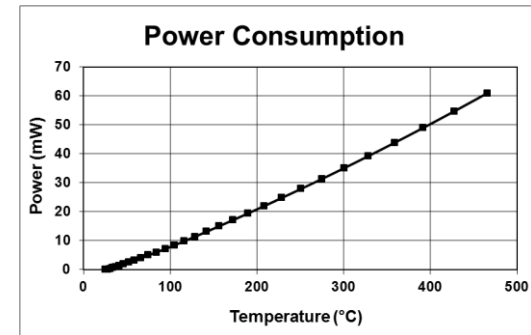
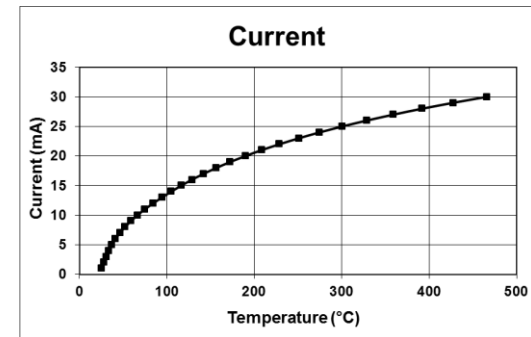
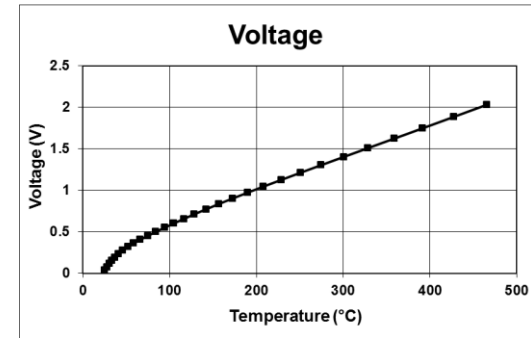
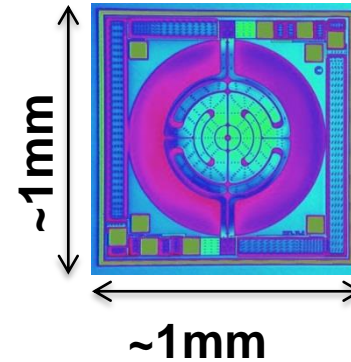
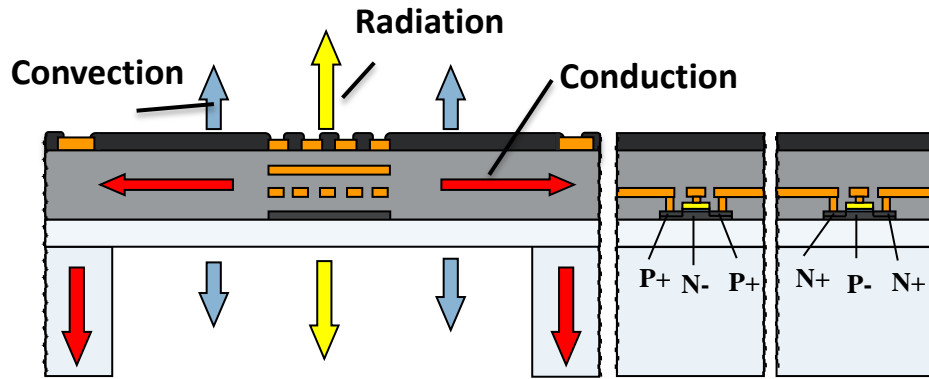
Reasons for Rapid Impact

1. The process perfected over more than 60 years
2. Proven to go beyond more than Moore's law
3. Billions of dollars invested in technology, methodologies and instrumentations
4. Billions of sensors already in production (microphone, accelerometer, hall etc.)
5. No other single technology that can be considered as a platform for true high volume
6. Offers scalability for lasting product life cycle and for future innovations
7. Integrated solution to enable smart multi-sensing capabilities
8. Wafer-level processing and packaging for 3D, heterogeneous packaged solutions
9. Provides high yield, low cost, ultra-miniature, low power solution
10. Great opportunity for CMOS sensor system-on-a-chip solution!

Components for CMOS AQM Sensor System

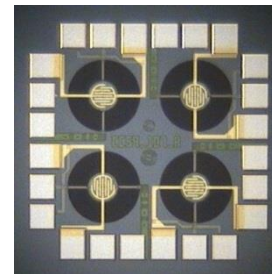
- Platform technology
- MOX Sensor
- Drive circuit
- Measurement circuit
- Calibration and compensation
- Signal Processing Firmware
- Software to display results and data logging

Platform Technology



Micro-hotplates integrated on standard CMOS process capable of:

- High Temperature (>500°C), High stability (< 1%)
- High reproducibility (99% Yield)
- High reliability (>5 years)
- Miniature device 1mm x 1mm die



Array of 2 x 2 MHP on 1mm x 1mm die

Platform for new generation of CMOS, MEMS Gas sensors, IR source and Detectors

MOX Sensor

Overview

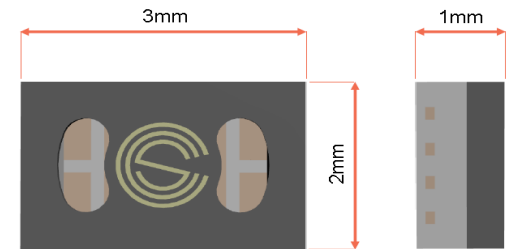
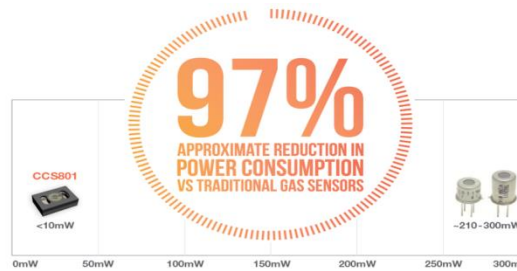
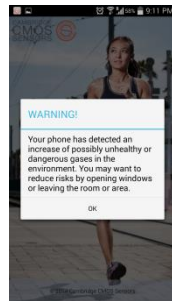
- Common foot-print SMD
- Serve multiple purposes and wide range of applications

Requirements

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

Solution

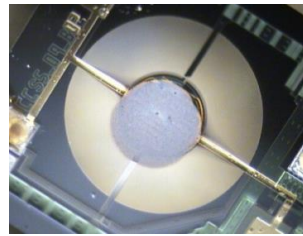
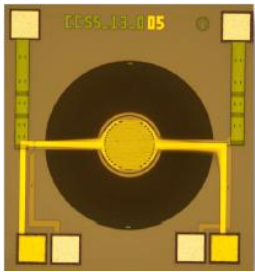
- Worlds smallest and lowest power gas sensor
- Supports IAQ / CO monitoring & alcohol breath analysis
- Fast response
- Sensor array for multi-gas sensing and redundancy
- Scope for further miniaturisation



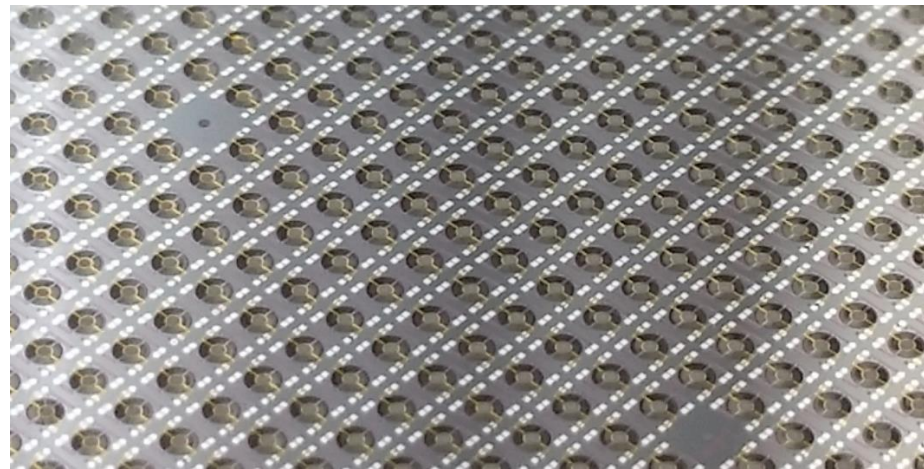
MOX Sensor package of AQM Application

- Use single chip designs
- With 1mm x 1mm die

Use low cost 2 mm x 3 mm SMD package



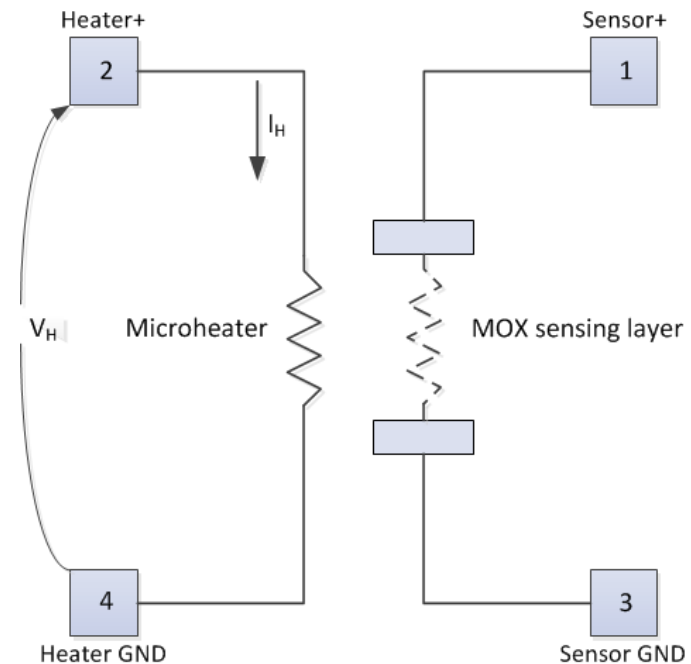
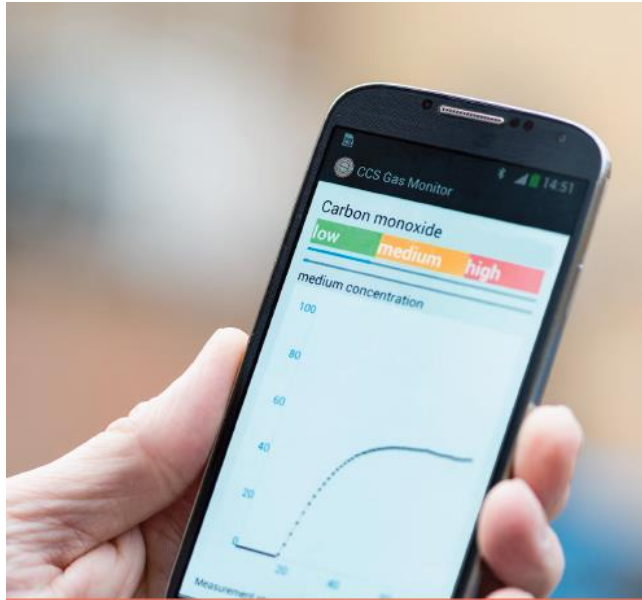
<10mW



More that 10K MOX Sensors on a single 6" wafer! Even more on larger wafer!

MOX Sensor Model

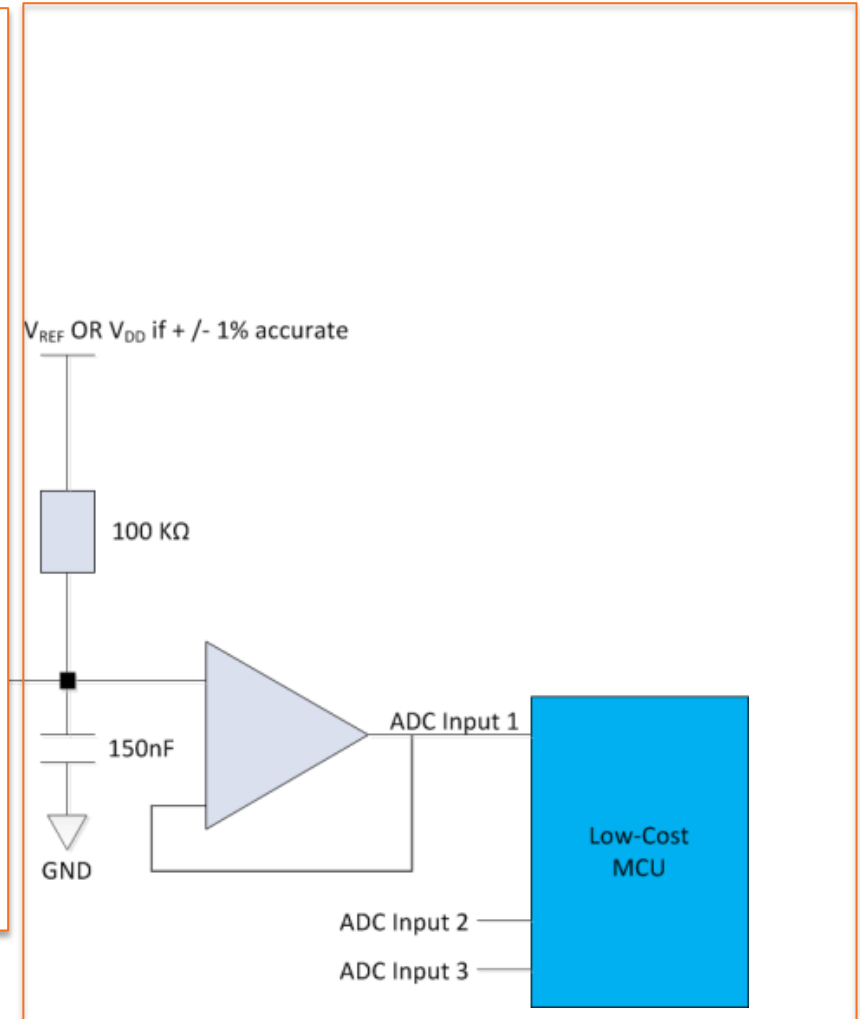
- MOX sensor is compatible with CMOS technology and process flow



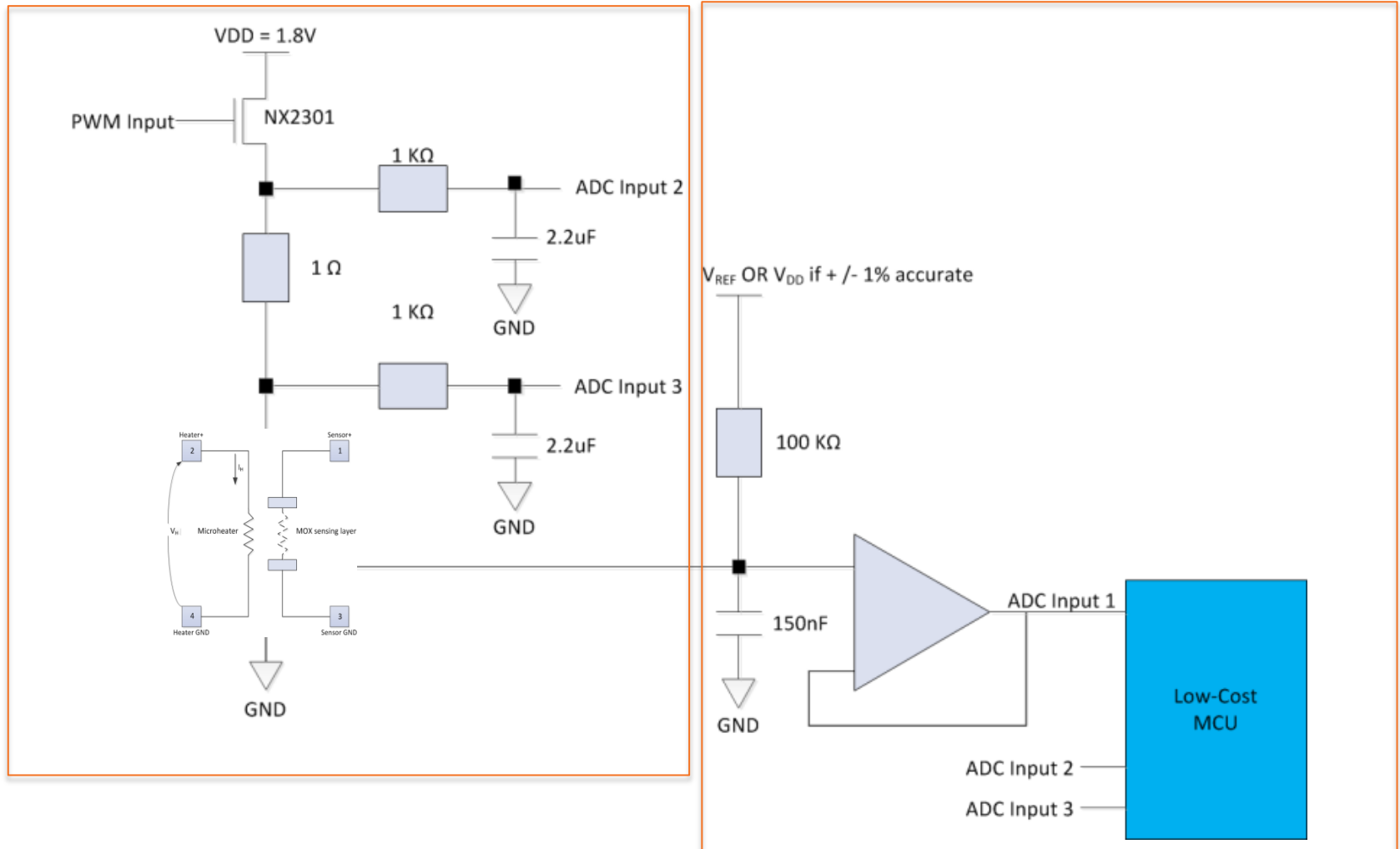
- A simple (or complex) sensor model can be developed and same EDA tool can be used for designing integrated systems solution.

Measurement Circuit

Keep Simple!

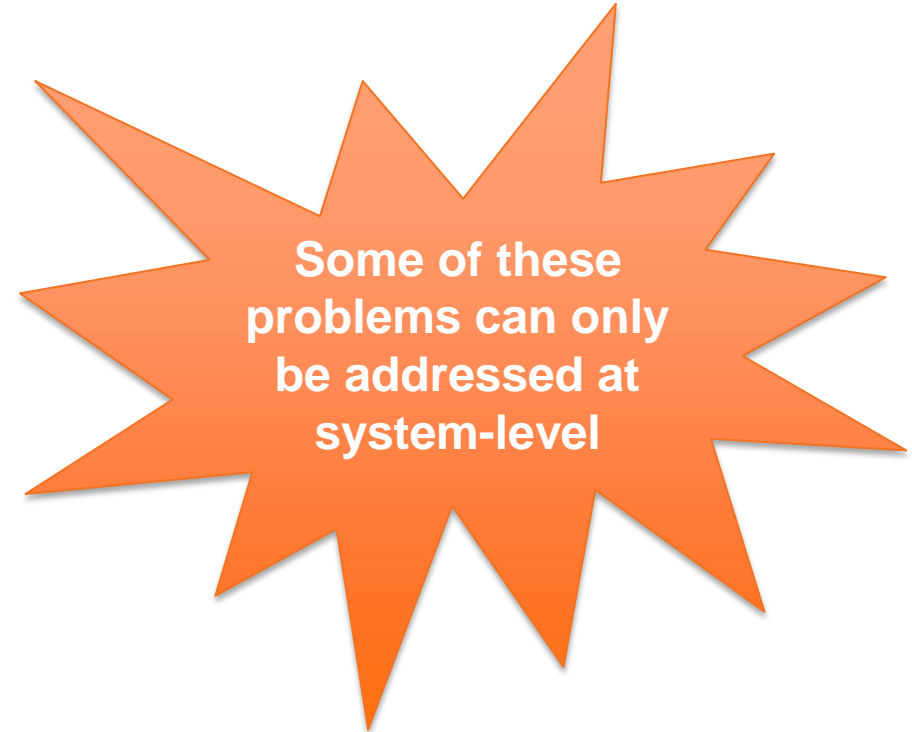


Drive + Measurement Circuit



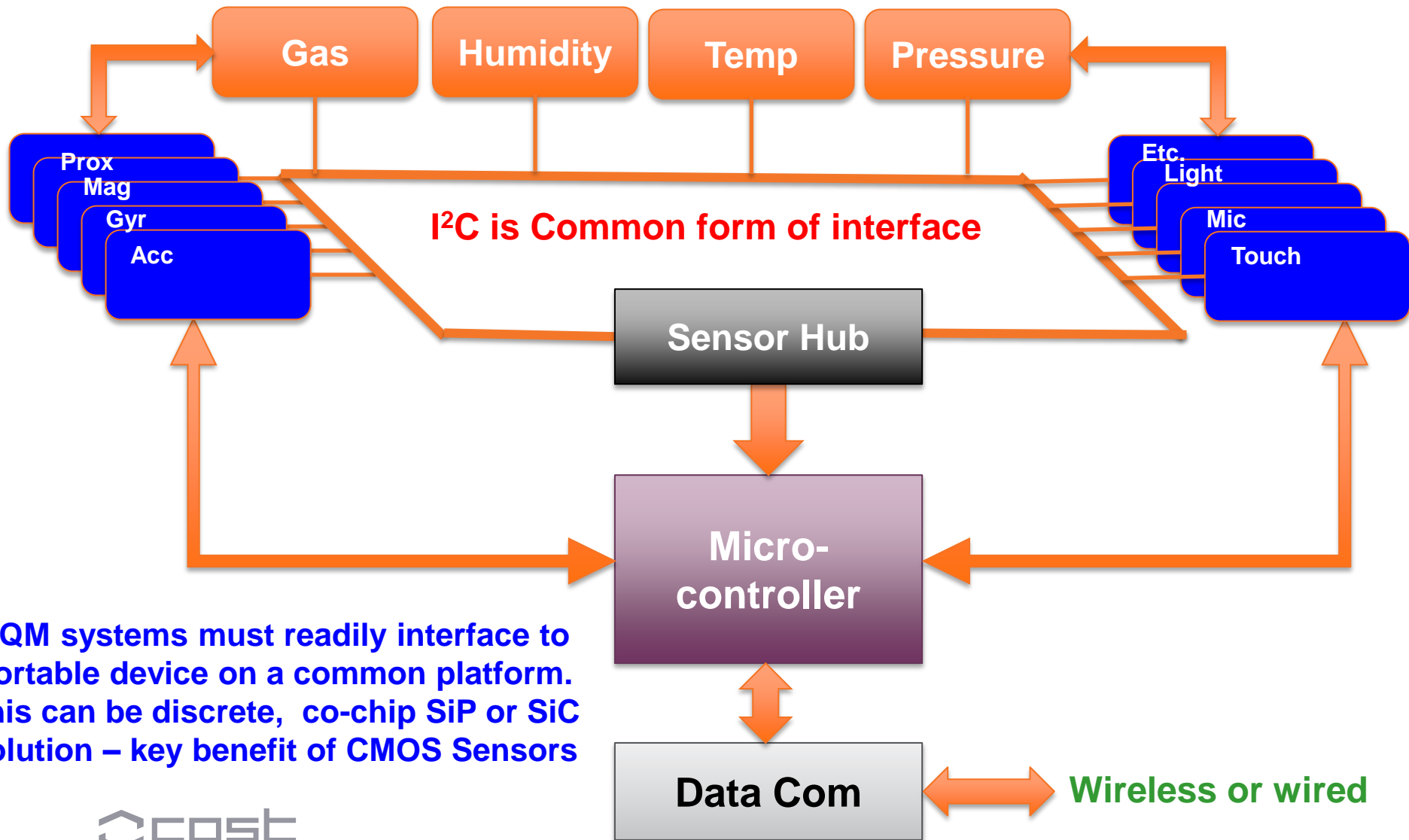
Factors that Influence CMOS AQM Sensor System

- Sensing material
- Heater temperature
- Drift
- Cross-sensitivity
- Response time
- Ambient condition
- Packaging



Hence there is a need for unified systems solutions to enable low-cost AQM

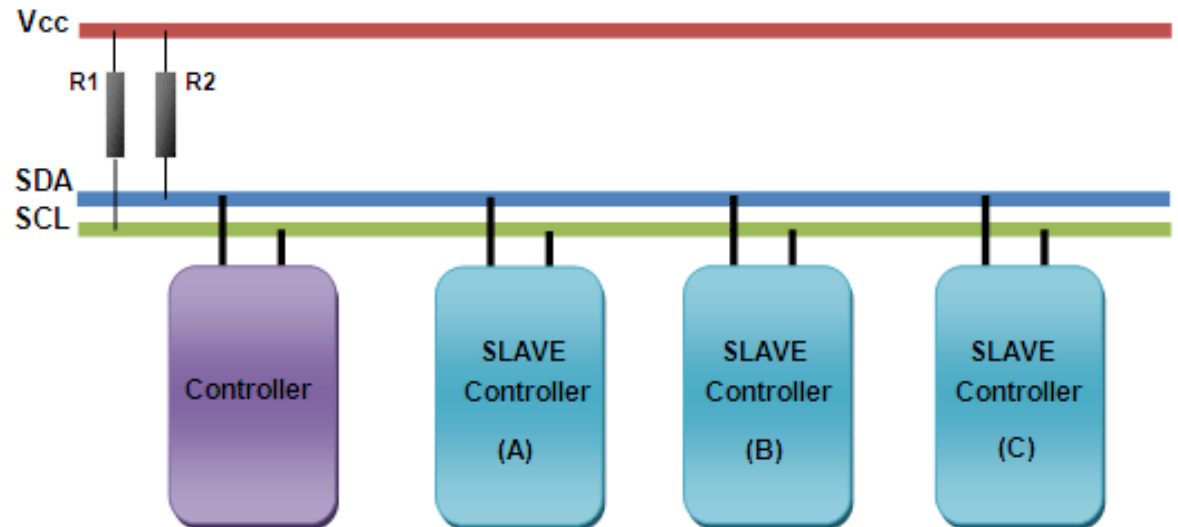
CMOS AQM Sensor System Platform



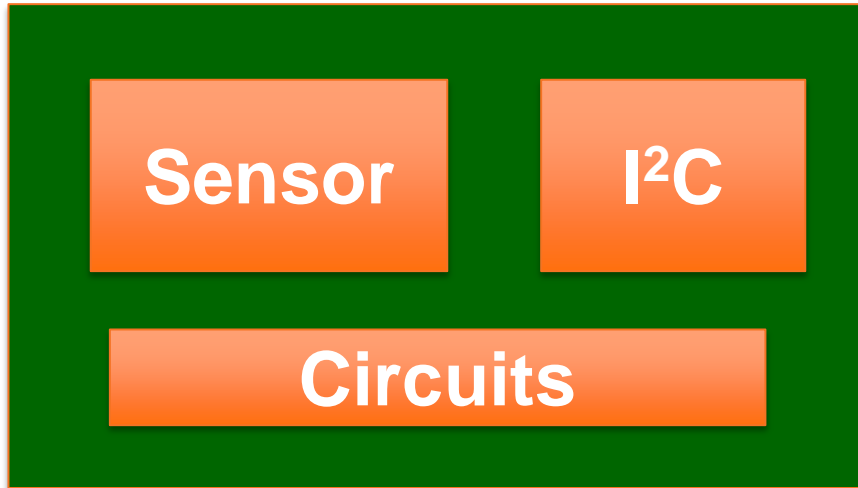
AQM systems must readily interface to portable device on a common platform. This can be discrete, co-chip SiP or SiC solution – key benefit of CMOS Sensors

I²C Overview

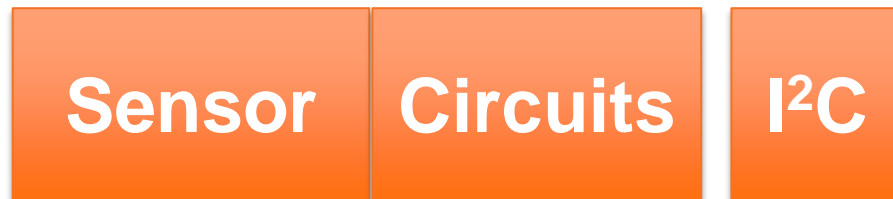
- Point-to-point communication – only 2-wires
- Select control signal is not required
- No clock required (Asynchronous)
- Data, Select and R/W share same line
- Only Controller can to “Slave” devices



CMOS Sensor Systems Options for AQM

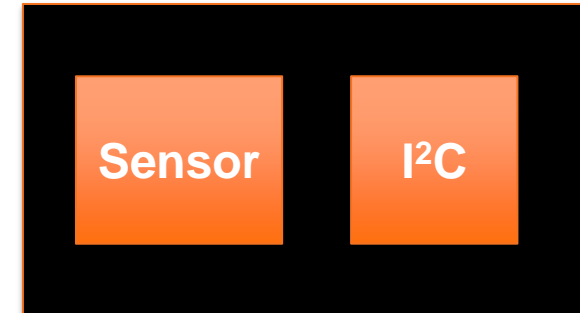


Discrete Component Solution on PCB

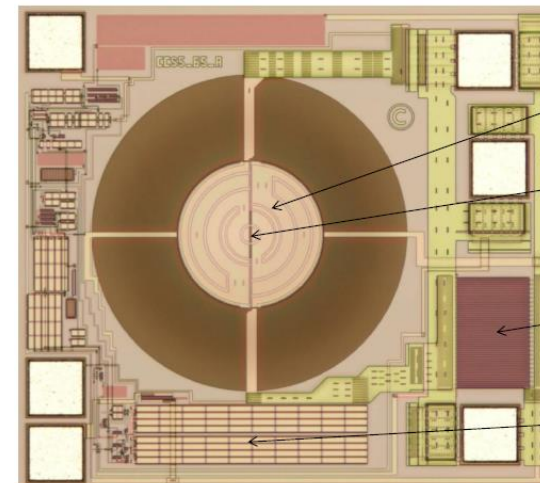


System-on-a-chip Solution

Option we choose depends on volume, cost and application!

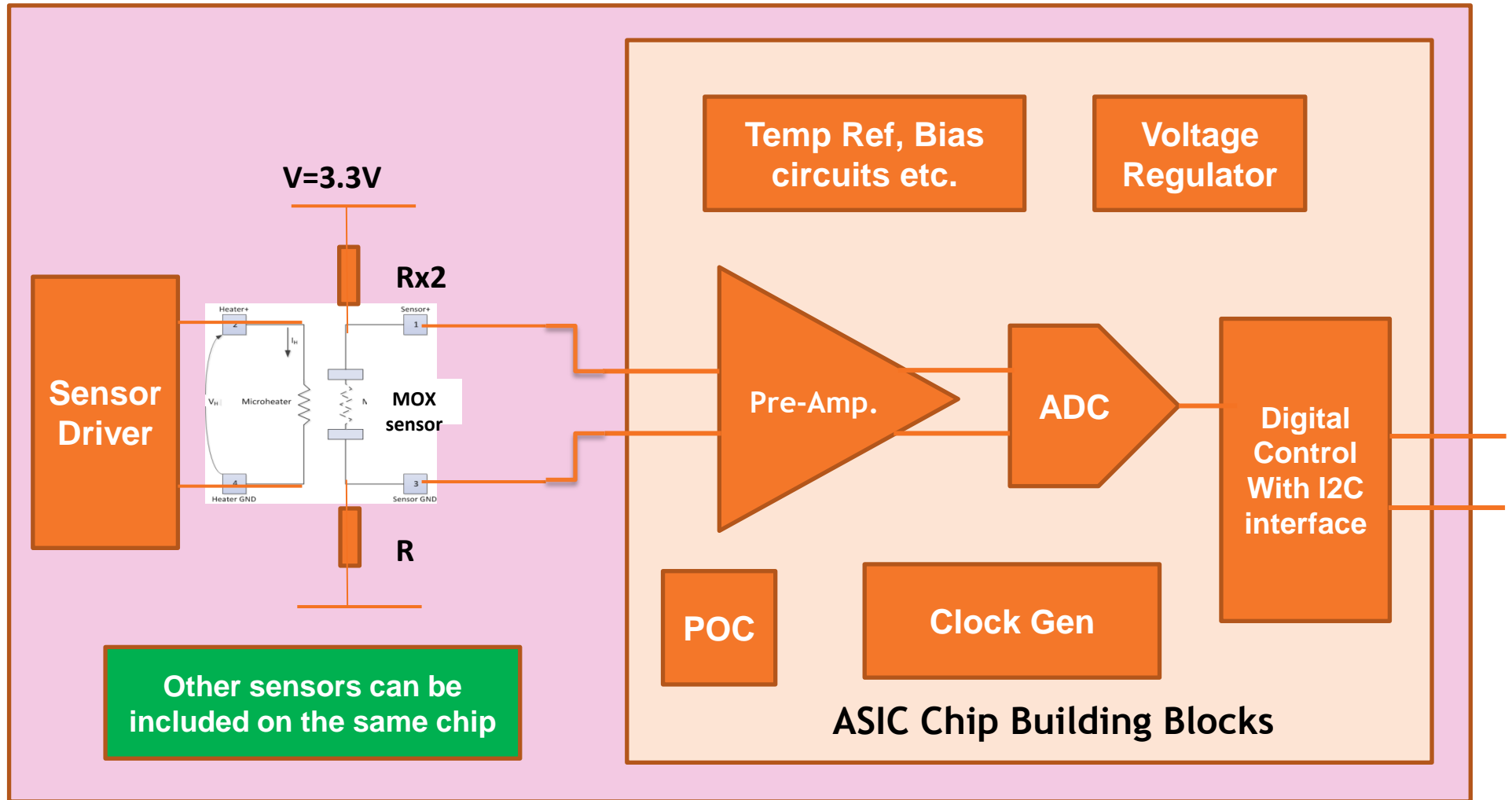


Co-chip SiP Solution (5mm x 3mm)



Advanced smart single chip ASIC design (1mm x 1mm die – excluding I²C)

Integrated CMOS AQM Sensor System

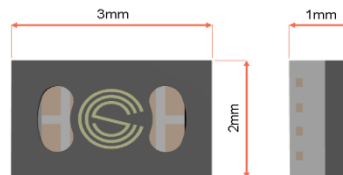


Example CMOS AQM Sensor System

AQM Sensor in Smartphone

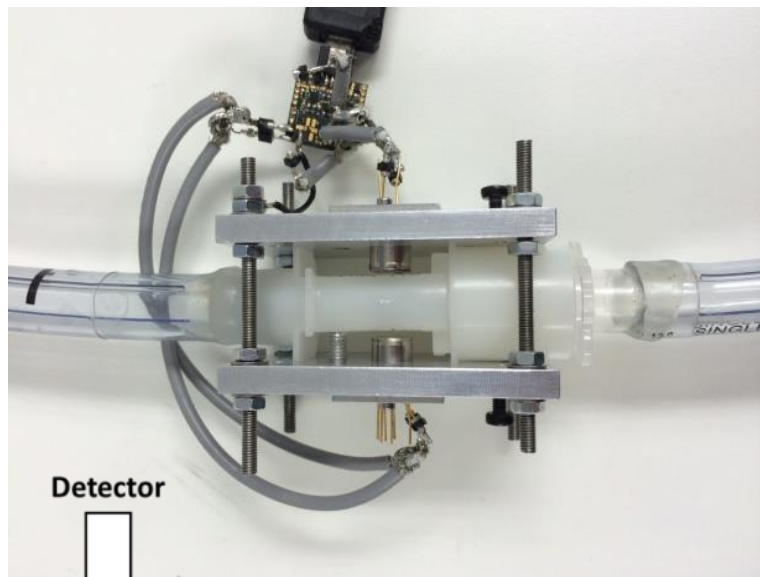


CMOS Sensor Evaluation Board



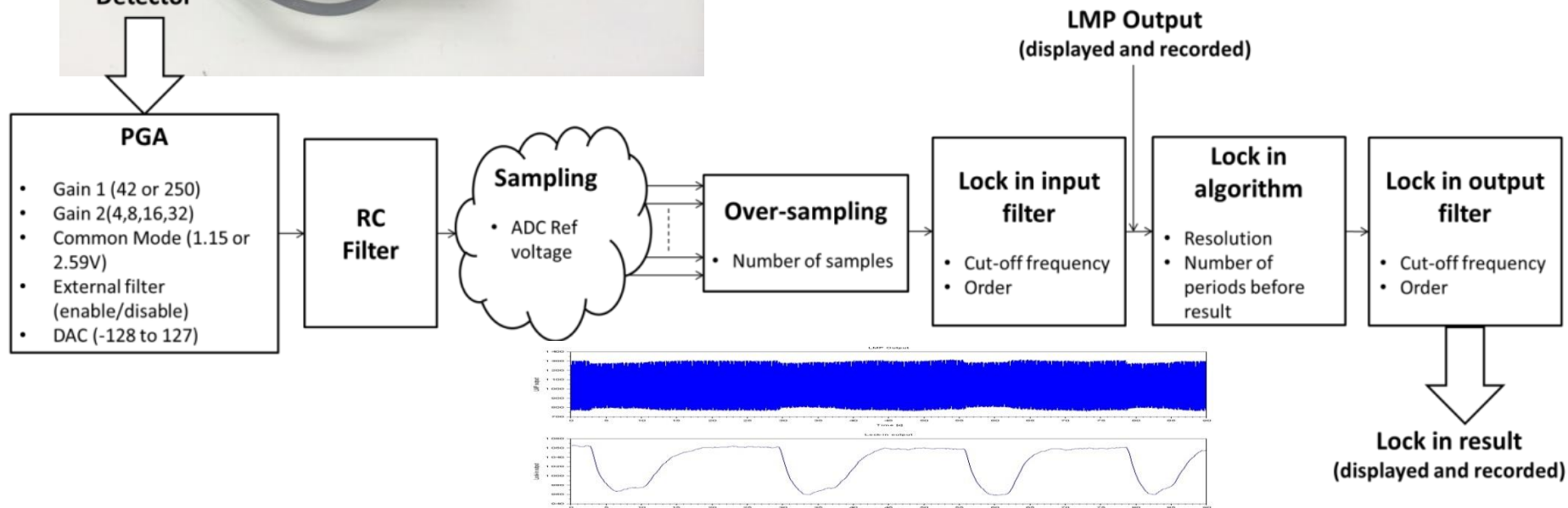
Measures: CO, VOC and Alcohol

High Concentration NDIR, CO2 System

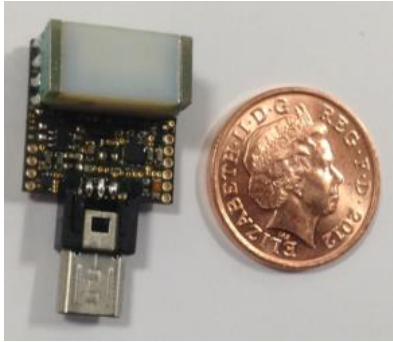


The tested prototype consisted of:

- NDIR board,
- In-house NDIR firmware
- IR CCS emitter & thermopile detector
- Optical reflectors
- A $4.26\mu\text{m}$ optical filter
- Two metal cases
- A tube and off-the-shelf airway adaptor
- A USB cable

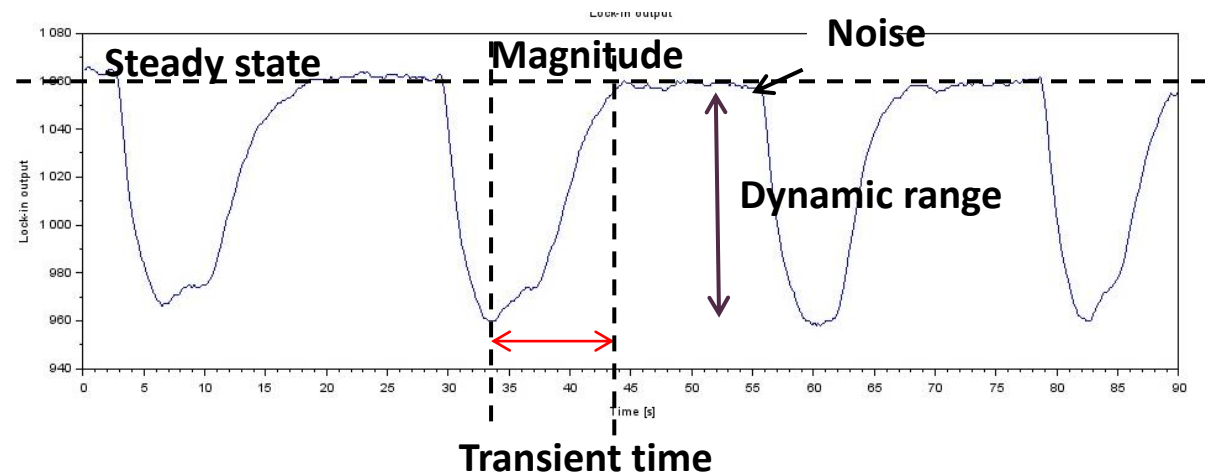
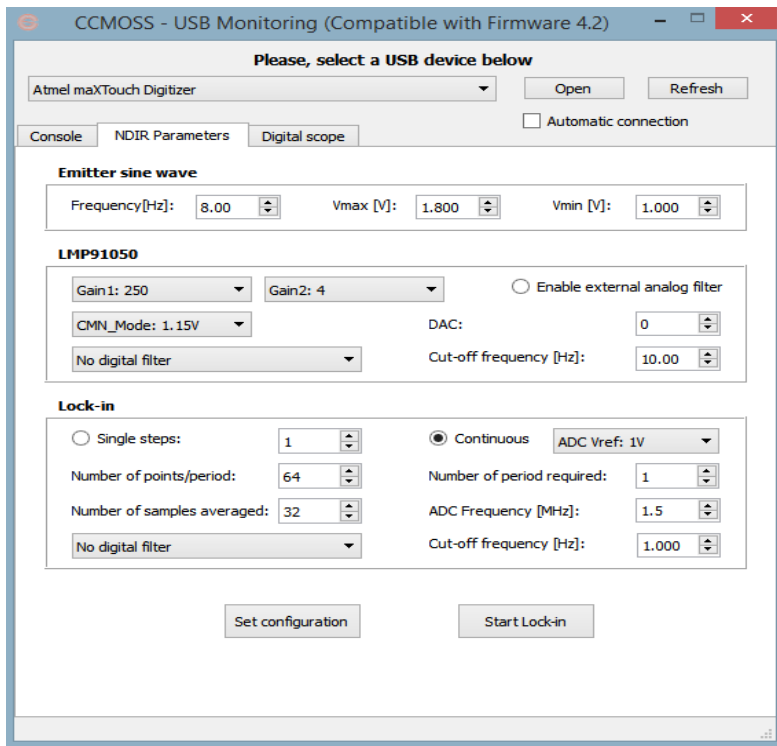


Mid-IR Emitter and Detector for CO2 Breath Analysis



The graphical user interface features:

- Communicate with the NDIR firmware
- Configure the NDIR firmware
- Real-time multiple signals visualisation
- Record data in Excel file or other format
- Stop and manage the display as desired
- Save the current configuration in a file
- Next step low concentration performance



90s breathing NDIR record Example

Some of the Facilities Available at CCMOSS



**Reliability Test Station
(banks of 8 sensors)**



Gas Test Stations



**Owlstone Permeation tube
Gas system (left)**



**Cambridge CMOS Sensors, Head office,
Cambridge, UK**

**Fabless company with 25+ staff
and Sales Offices in Taiwan and China**

Current activities

- *Micro-hotplate development for >700°C operation*
- *IR Emitter and detectors - for Mid-IR Gas sensing and thermometry applications*
- *Small Sensor Development – For smartphone application*
- *Smartphone for AQM – application solutions*
- *Looking at indoor AQM – portable low cost modules*
- *Outdoor AQM – more robust and improved accuracy*



Current EU Projects activities

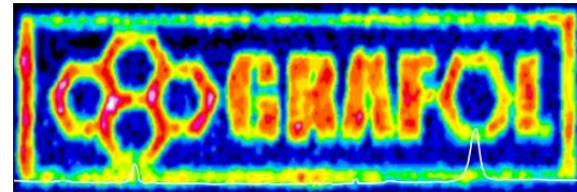
- SOIHITS (Harsh Environment)



- MSP (3D TSV Packaging)



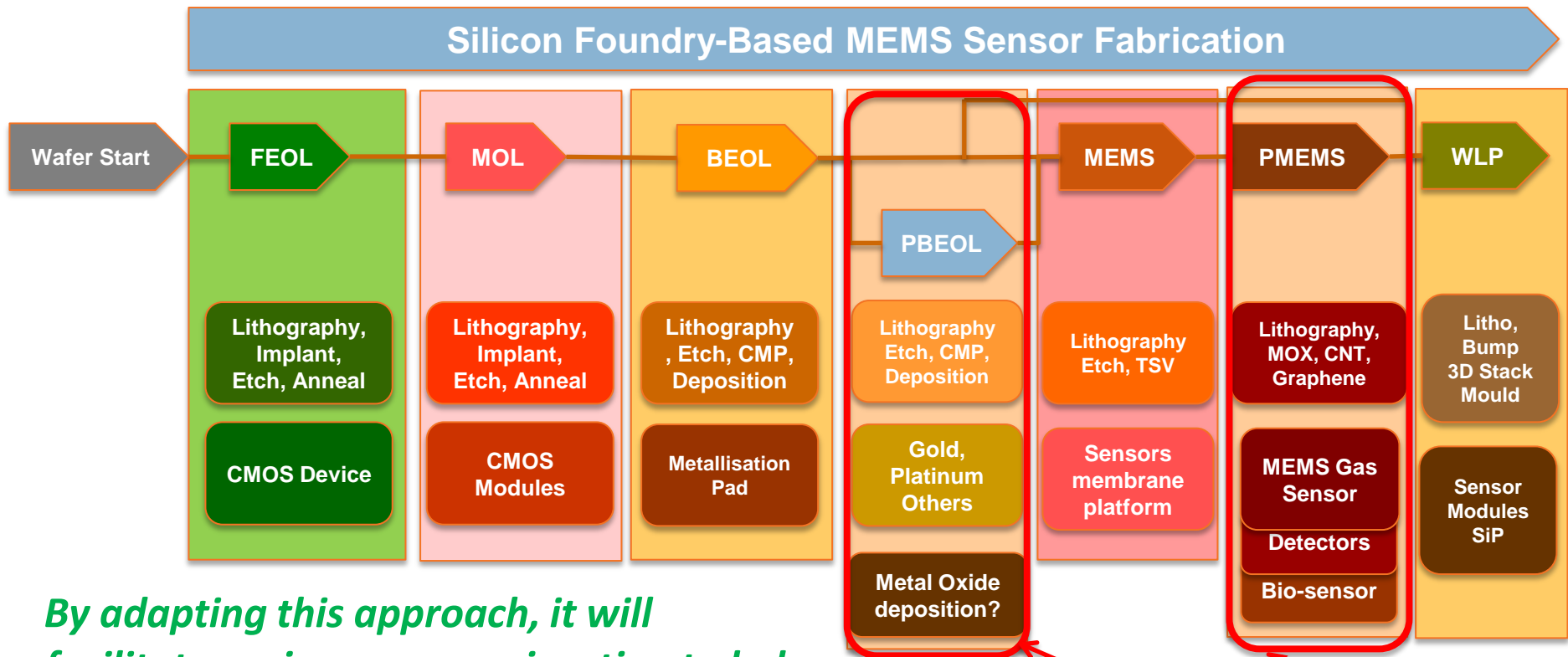
- GRAFOL (Advanced Material)



- E2SWITCH (Ultra-low voltage)



Future Activities



By adapting this approach, it will facilitate easier process migration to help keep pace with technology scaling.

Critical Steps for high volume Sensors

Unified method of enabling high volume sub-miniature MOX and other sensors by exploiting CMOS technology -> improve sensitivity, selectivity and reliability

CONCLUSIONS

- *CMOS Sensor system, MEMS and non-MEMS is a true enabler for low cost applications*
- *More and more exotic sensors are being integrated in portable devices such as smartphones, wearables and tablets*
- *CMOS sensor systems are perfectly aligned for this purpose*
- *Any AQM sensors will need to follow same interface protocol as other sensors that are already being integrated in such system*
- *By following this protocol more advanced data processing, compensation and calibration can be done to improve accuracy and selectivity*

Acknowledgements

Founders, Investors and Team at Cambridge
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COST Action

