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New Trends and Challenges for Air Quality Control

University of Latvia - Faculty of Geography and Earth Sciences

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Silicon-on-Insulator Micro-hotplates Platforms for Humidity Sensing: Follow-up of the Air Quality Intercomparison Exercise

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The research context

Combustion process monitoring

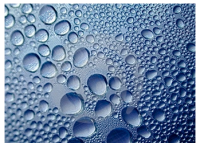
- FP7 SOI-HITS: System-in-Package demonstrator for domestic boiler monitoring (More-than-Moore roadmap)

- Methane combustion process :

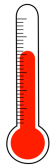
  $CH_4 + Air \rightarrow CO_2 + H_2O + CO + NO_X$

- Measurements of CO_2, O_2, CO, %RH and T above the burner, i.e. up to 225°C

SOI-HITS
Smart Silicon On Insulator Sensing Systems Operating at HIgh Temperature



Humidity



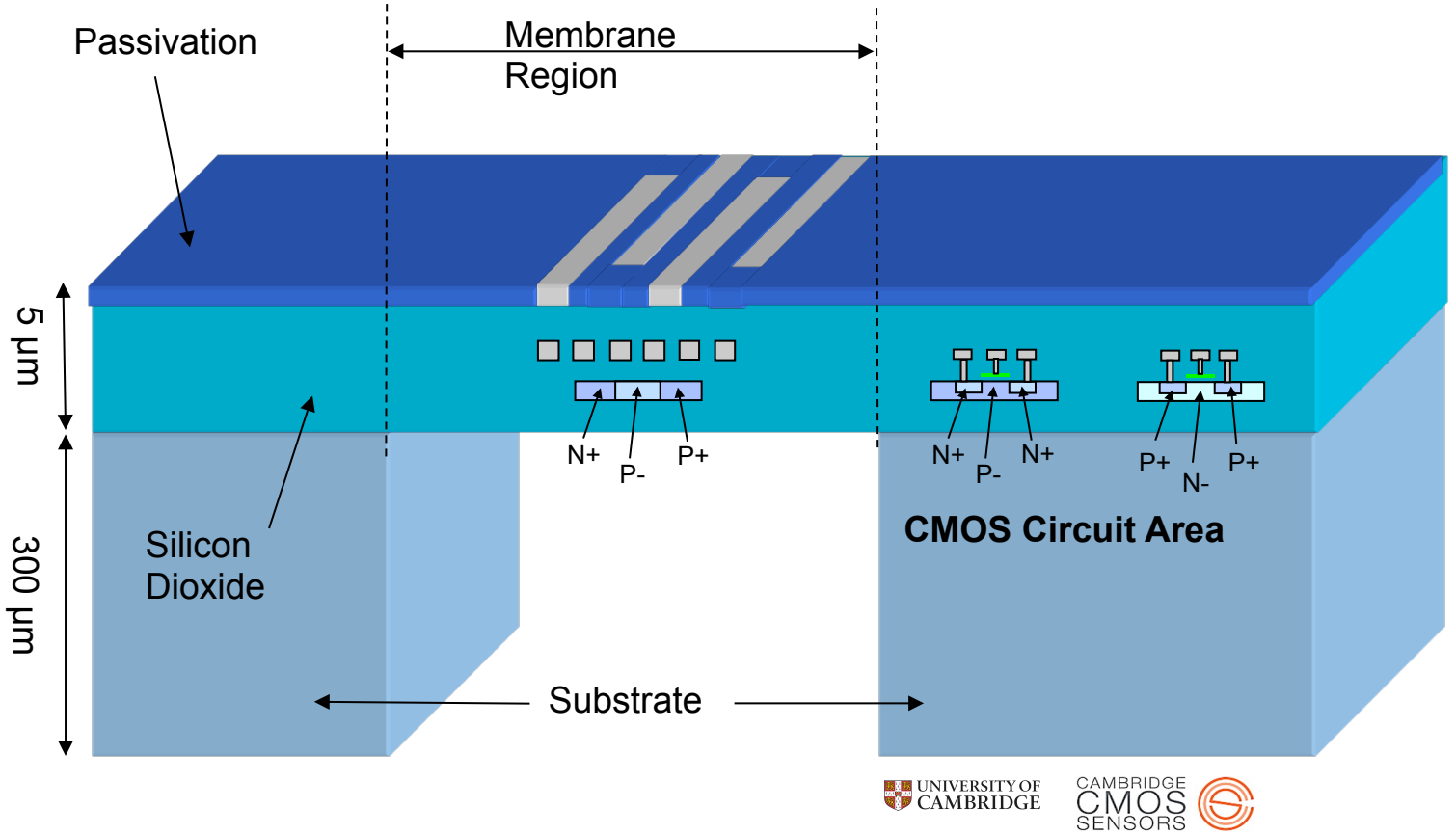
Hot

Best boiler tuning

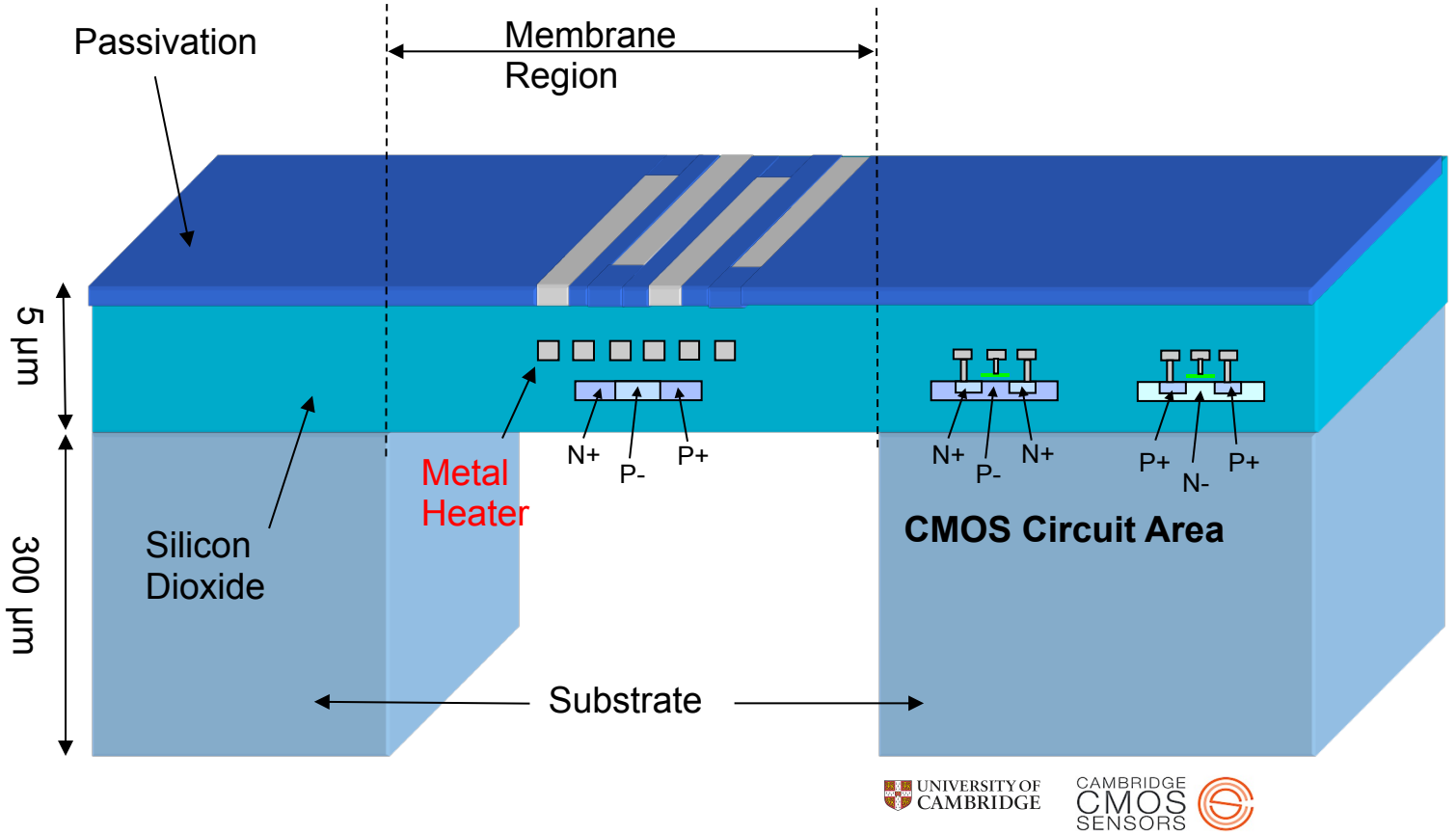
Microsemi Honeywell CISSOID IREC UCL Université catholique de Louvain THE UNIVERSITY OF WARWICK UNIVERSITY OF CAMBRIDGE CAMBRIDGE CMOS SENSORS

Sensor platform description

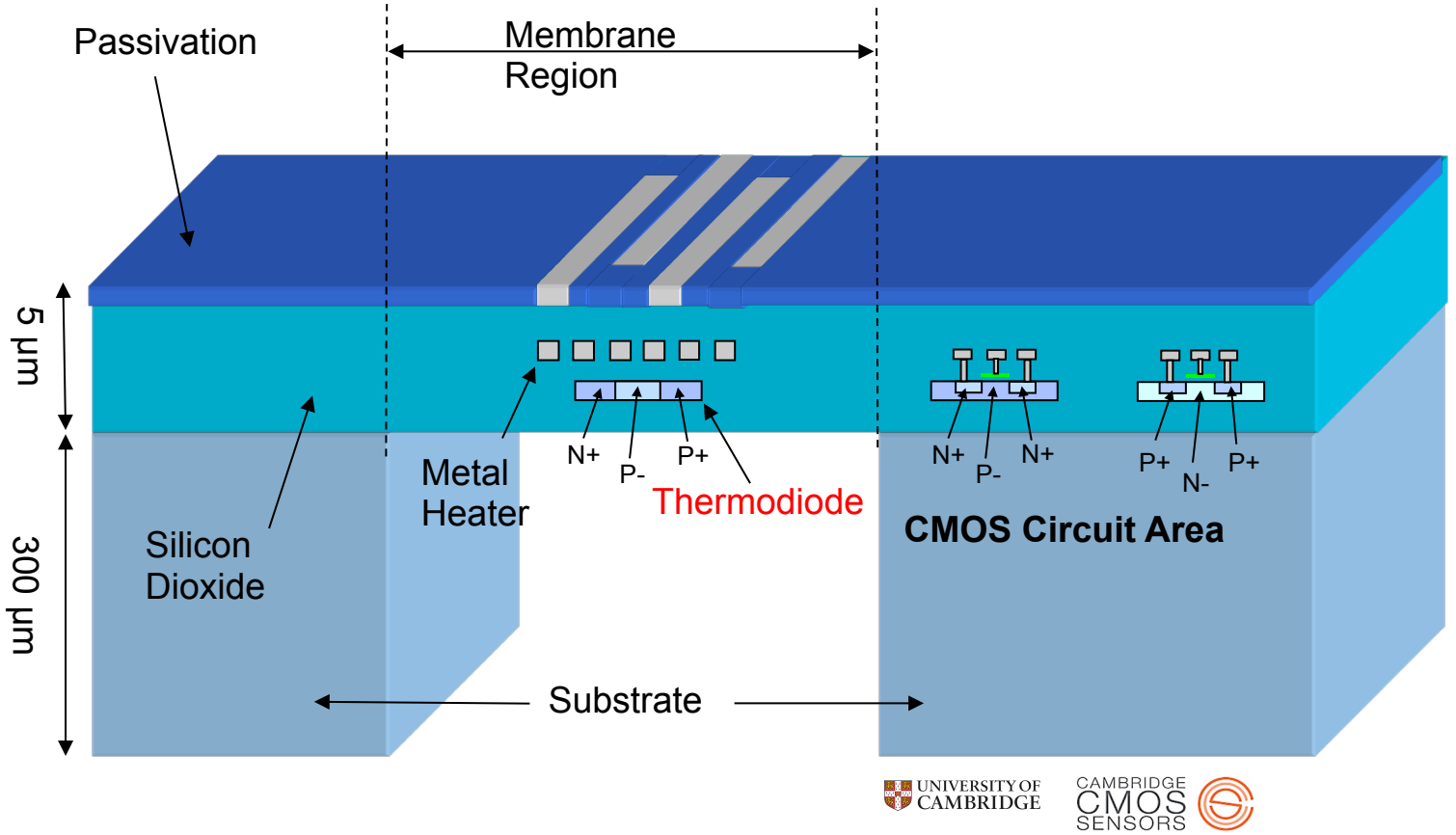
Micro-Hotplate SOI Sensor Platform



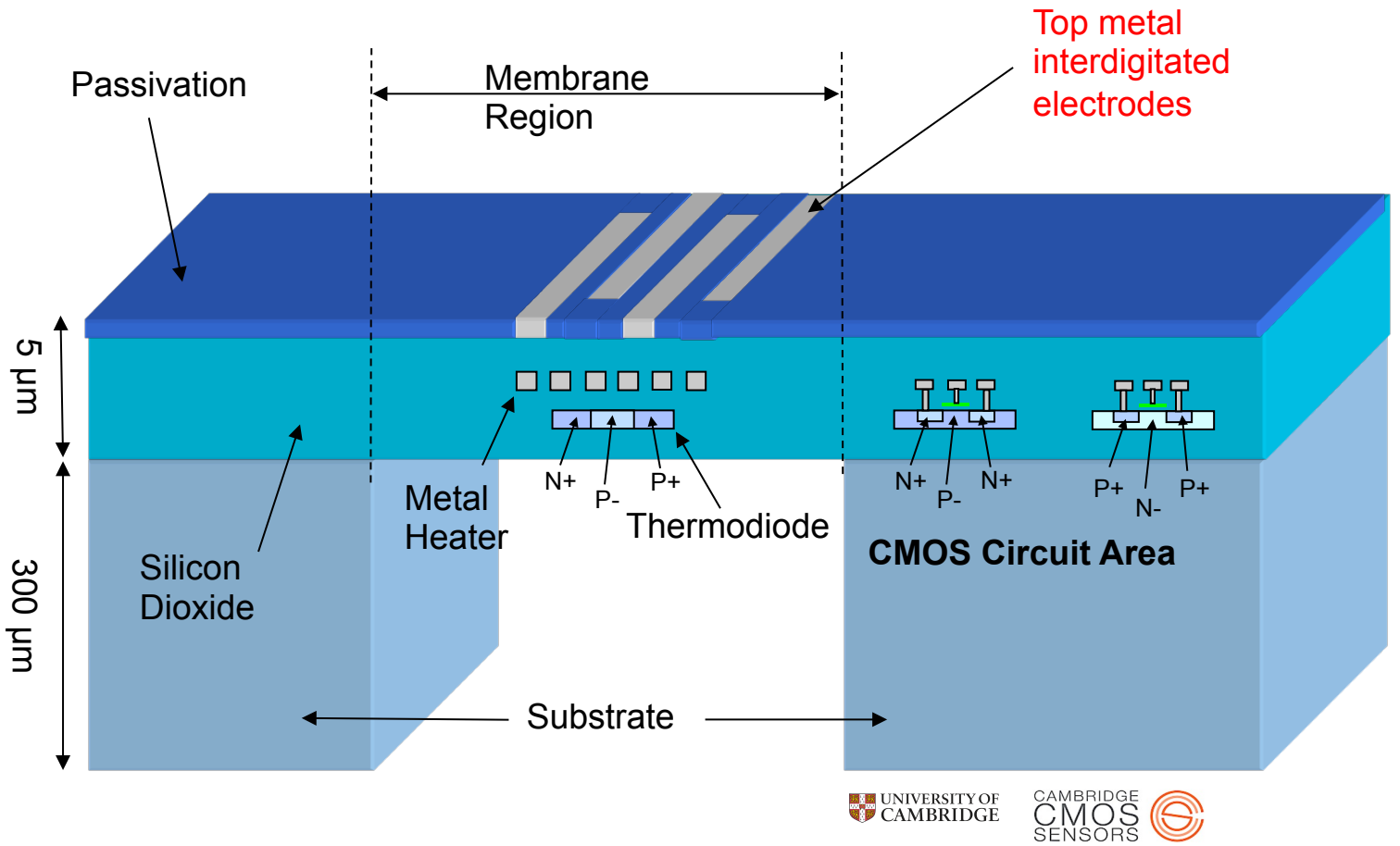
Micro-Hotplate SOI Sensor Platform



Micro-Hotplate SOI Sensor Platform

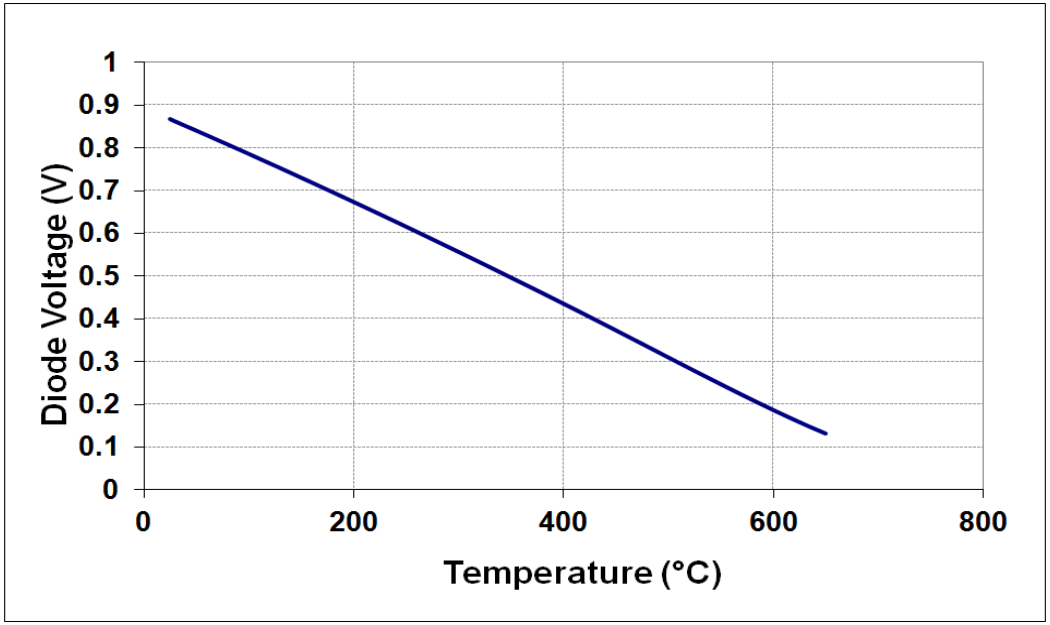


Micro-Hotplate SOI Sensor Platform



Micro-Hotplate SOI Sensor Platform

- Electrothermal properties:
  - Very good insulation,
  - Low thermal mass,
  - Heater: 35 mW for 600°C,
  - Thermal transient time: ↑10 ms, ↓20 ms
  - Long term testing: 2% resistance variation for 10.000 h/10 Hz/400°C,
  - Thermodiode: ~1 mV/K up to 600°C
  - Reproducible across wafer

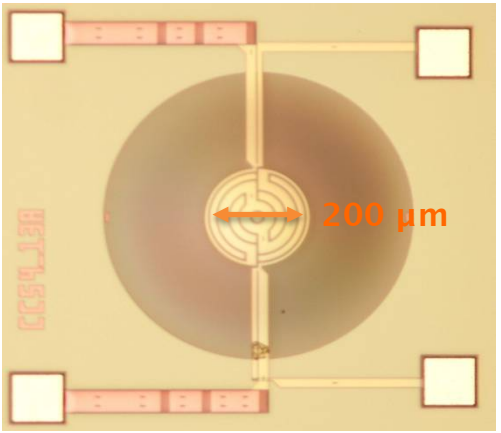


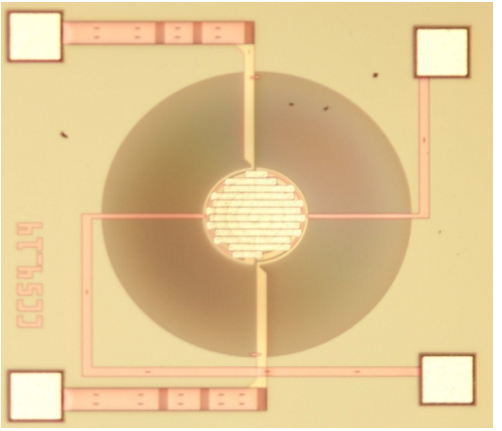
Thermodiode forward biased at 65 µA

Micro-Hotplate SOI Sensor Platform

- Gas Sensing :
  - Calorimetric
  - Impedimetric: with electrodes
  - Differential measurements
  - Various metals
  - Co-integrated IC possible

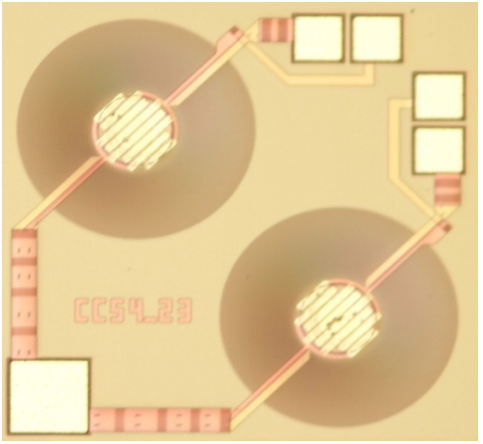
Basic micro-hotplate chip

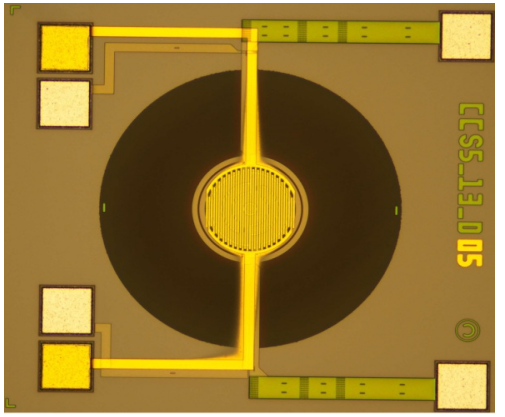




UNIVERSITY OF CAMBRIDGE

CAMBRIDGE CMOS SENSORS





Water vapour sensing

Commercial humidity sensors

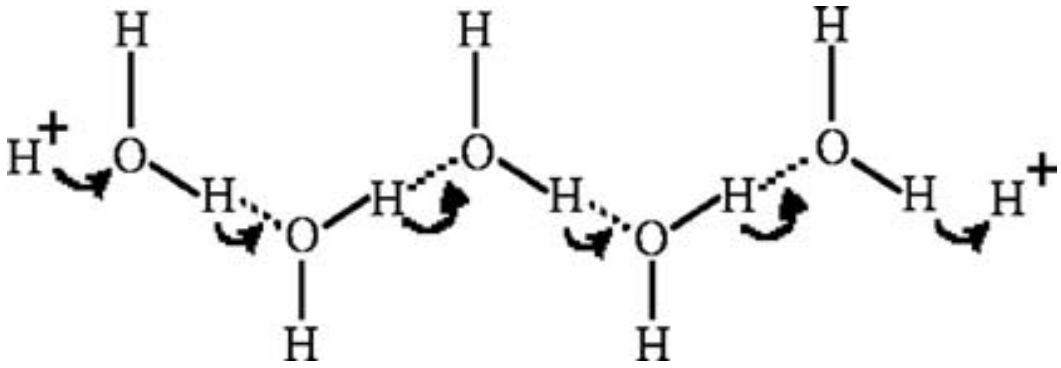
- Technological trends:
  - widespread use of polymer as PI - easy to process and linear response
  - thin and porous ceramic materials - lower time response

Honeywell HCH-1000 Series
Typ. 5 € piece
-40°C to 120°C
Response time 15 s
Polyimide

Sensirion CMOS SHT21
Typ. 4 € piece
-40°C to 125°C
Response time 8 s
Polymer

Our humidity sensor

- **Sensing principle: ceramic Al_2O_3**



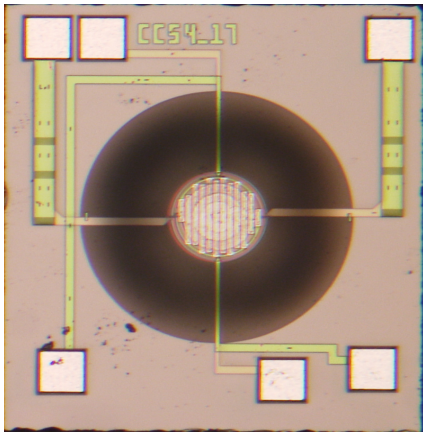
- ***Grotthuss* mechanism with ceramics like Al_2O_3 (hydroxyl-terminated) for physisorbed layers**
  - ✧ **Protons hoping through hydrogen bonding with E field**
    - → **conductivity increase**

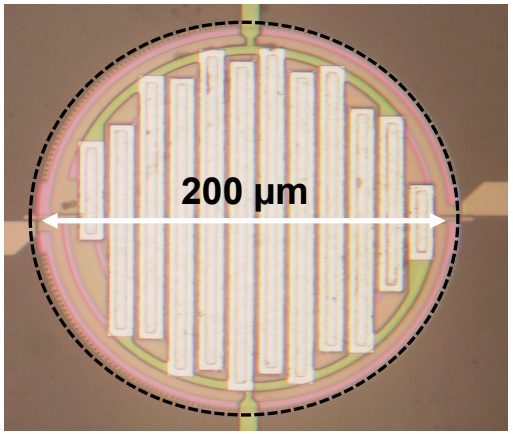
- **Addition of water molecules, free to orient themselves**
  - → **dielectric constant increase**

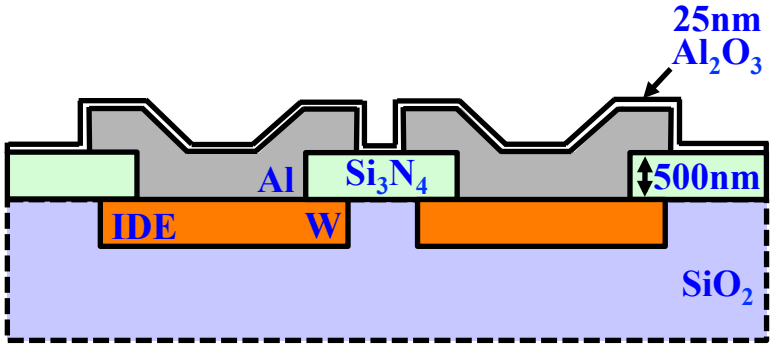
Our humidity sensor

- Aluminum oxide coating on interdigitated electrodes
  - ✧ Surface adsorbed water on this hydrophilic metal oxide

- Optional:
  - ✧ heater for fast recovery after condensation, anti-drift methods and cleaning
  - ✧ local T to determine the %RH point



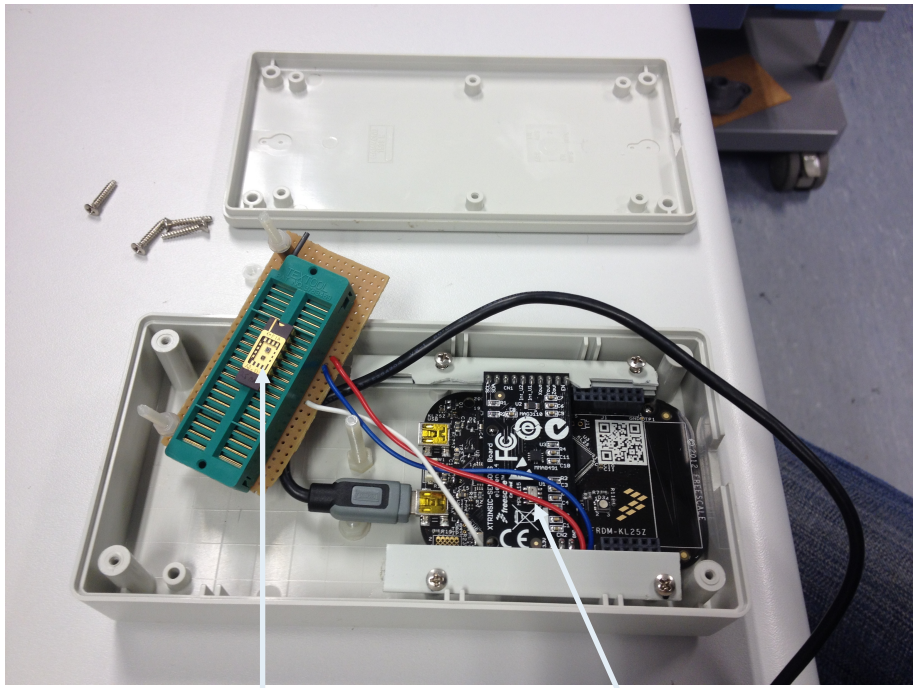




Results

Aveiro experience set-up

- Portable system = Micro-hotplate + Read-out circuitry + Freescale KL25Z® + Acer® Netbook



Our %RH sensor

MLP315
T sensor on Freescale board

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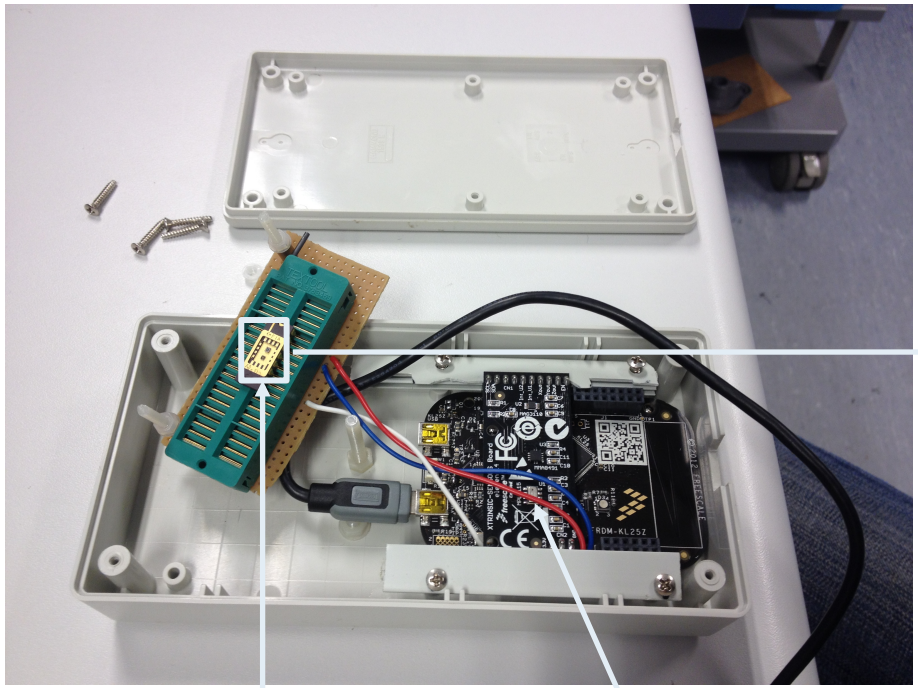
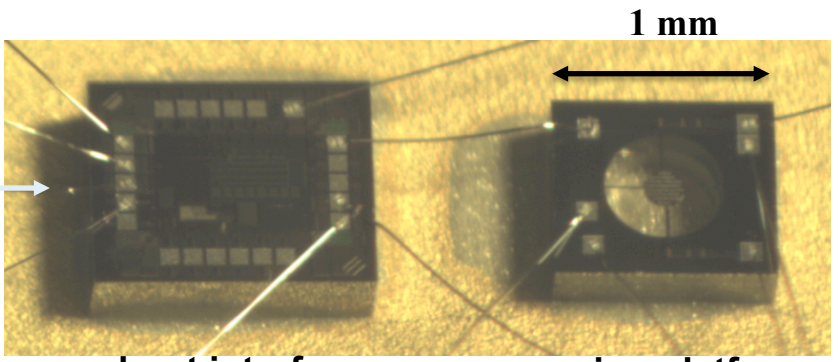


Our %RH sensor

MLP315 T sensor on Freescale board



read-out interface
=
ring oscillator

sensing platform

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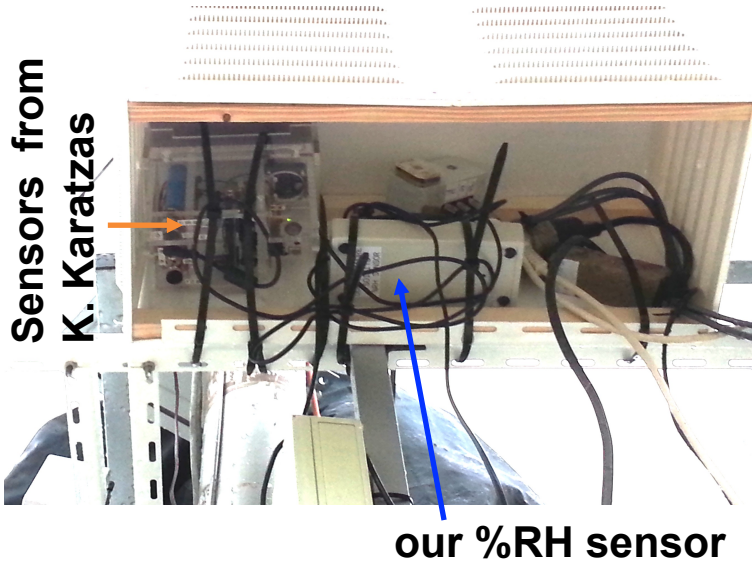
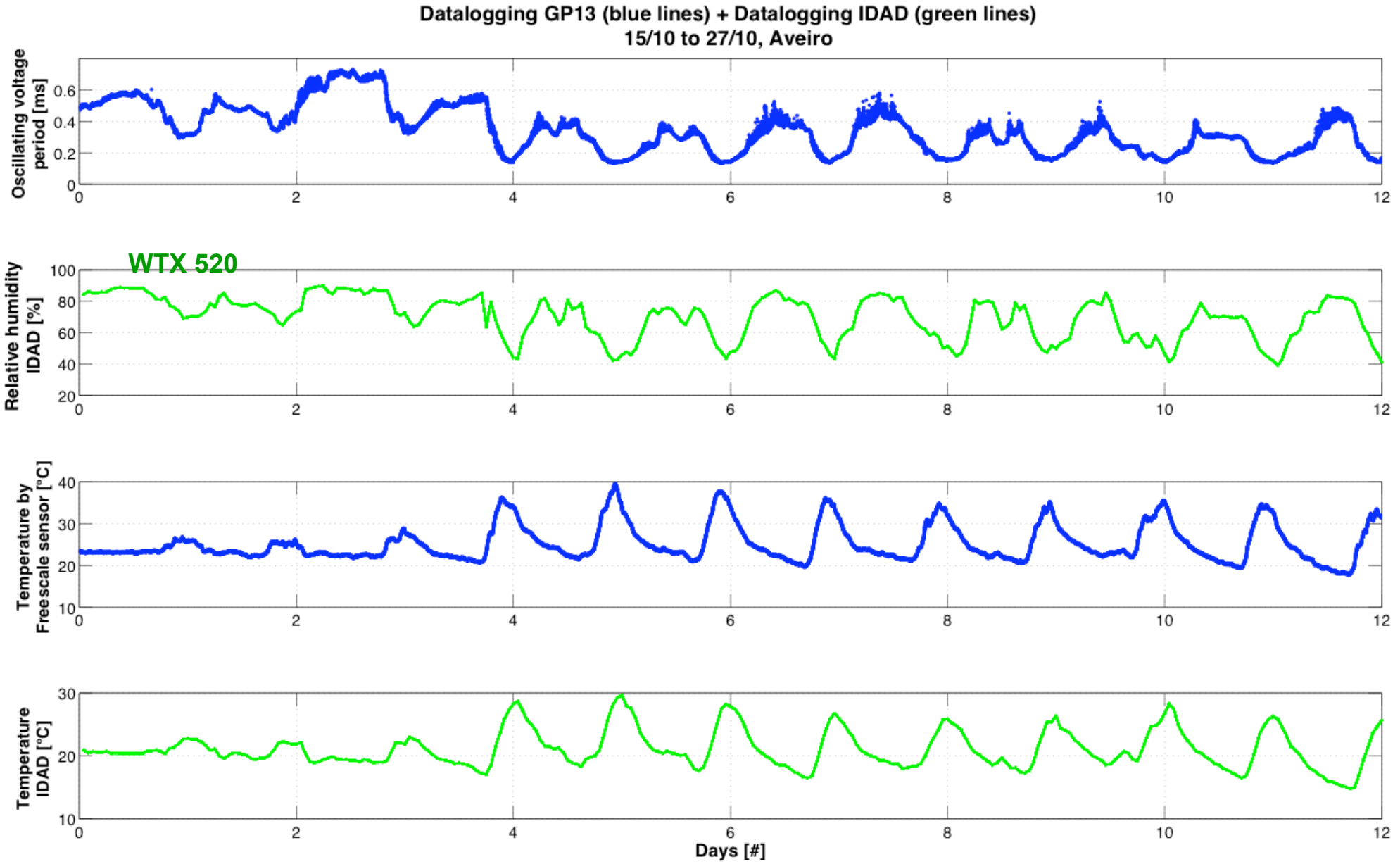


Aveiro experience results



Aveiro experience set-up

- How to compare the possible reference with our sensor?
  - Discrepancies between %RH and T sensors dispersed on the car:
    - WTX520; GrayWolf; K. Karatzas
    - As large a 5 °C
    - As large as 25%RH
  - Larger discrepancies for our T sensor MLP315:
    - As large as 9 °C
    - Thermodiode on micro-hotplate not implemented for datalogging at that time

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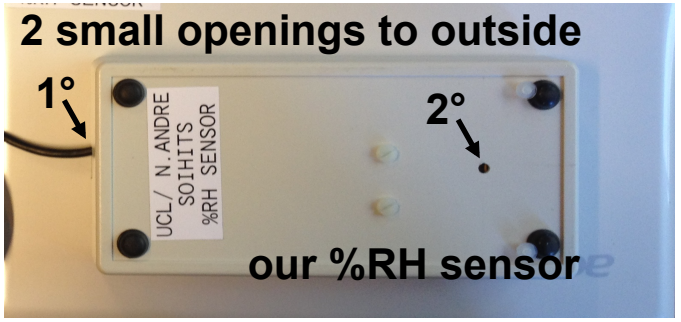
    - Thermodiode on micro-hotplate not implemented for datalogging at that time
  - Errors, sun exposition, ventilation, packaging, self-heating and possible condensation considerably influence the local atmospheric conditions



  - Complexity of the comparison exercise: many unknowns! -> machine-learning

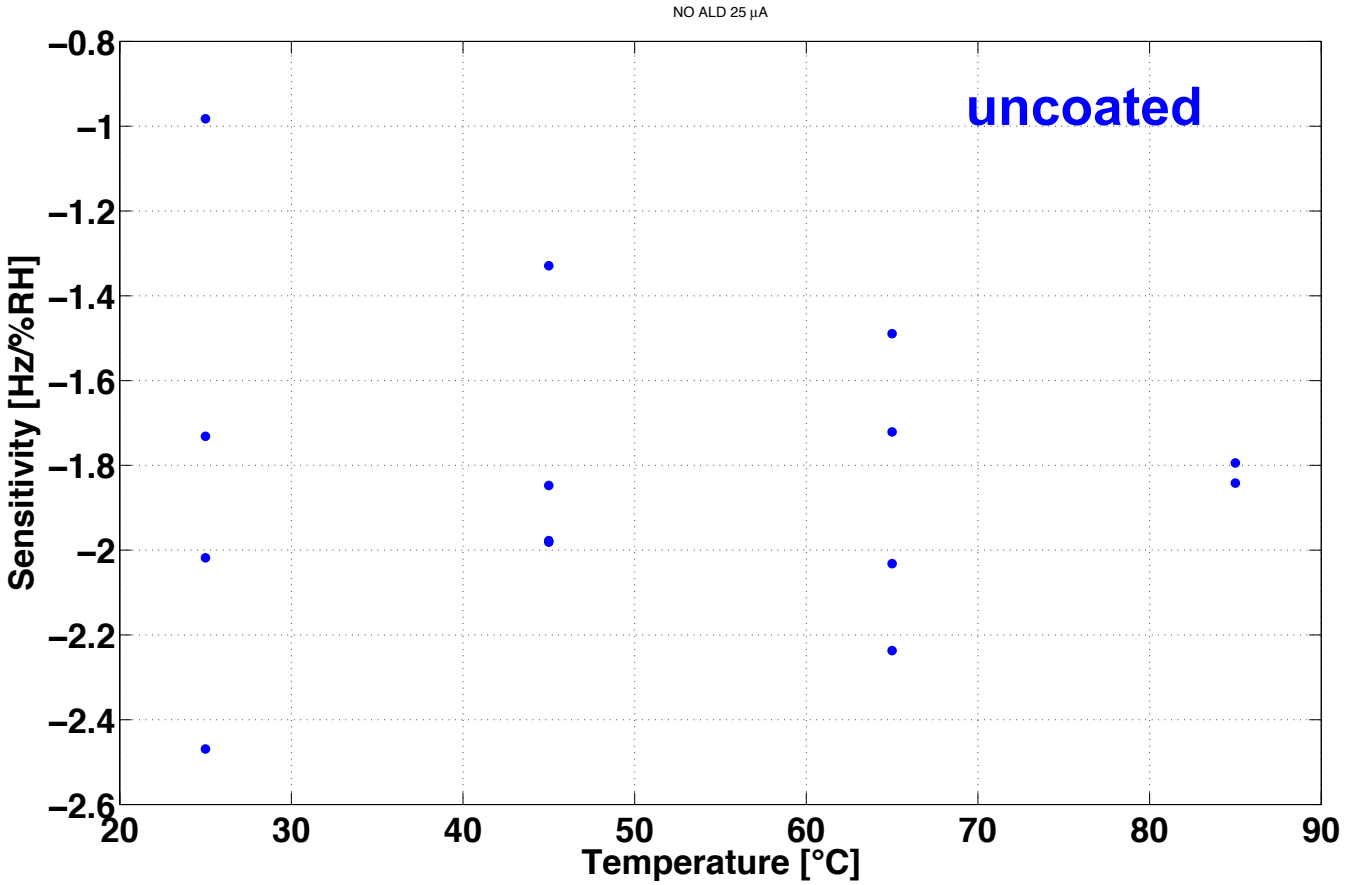
Climatic chamber experience set-up

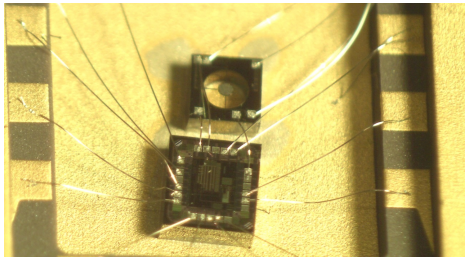
- Come-back to a controlled environment
- Oscillating voltage period measurements under variable %RH and T

ESPEC SH-261:
- **15 to 35°C,**
- **45 to 90%RH**

Climatic chamber experience results

- Al_2O_3 coated vs uncoated microhotplate





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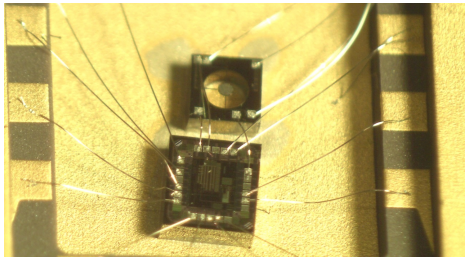

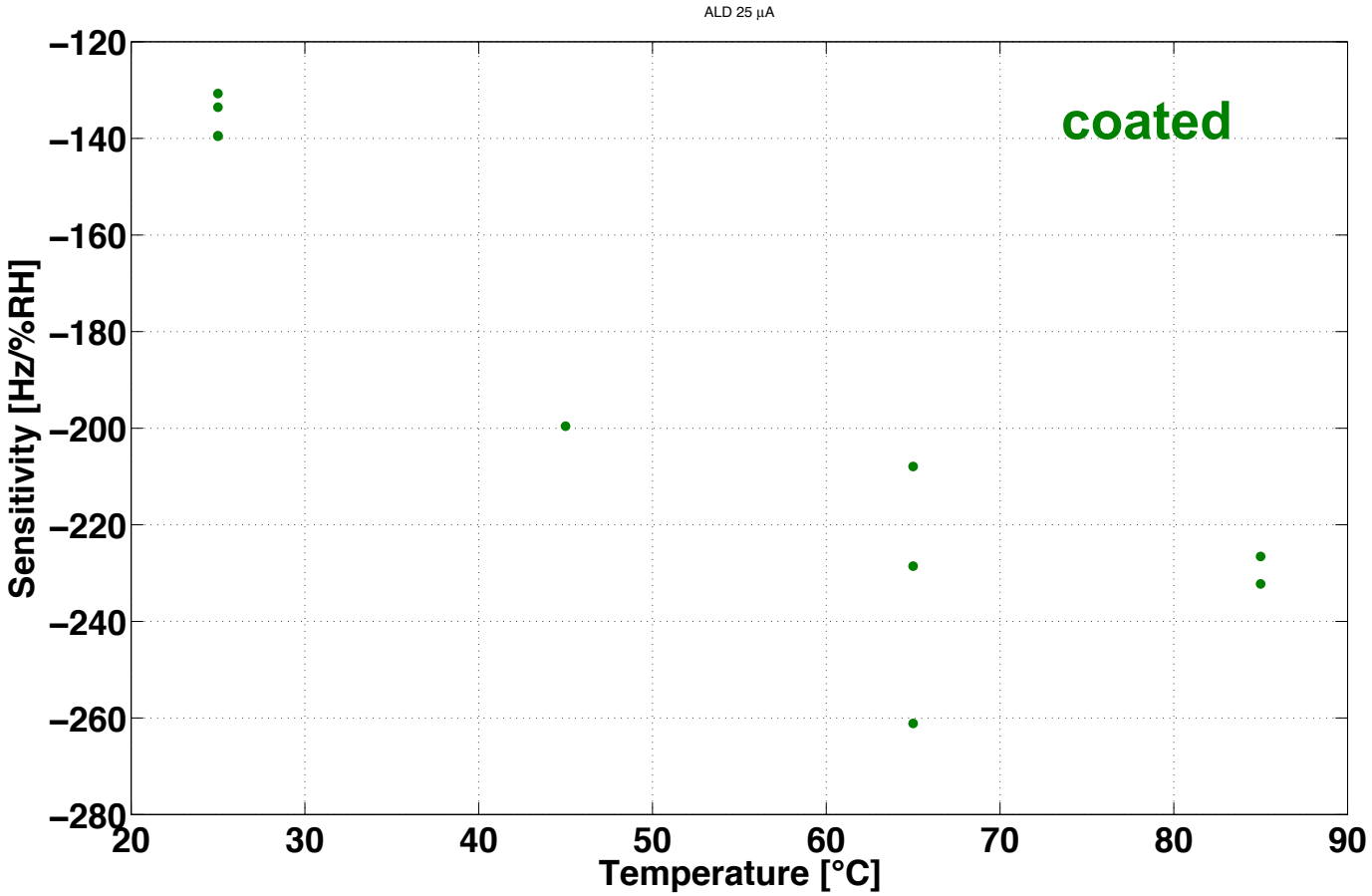

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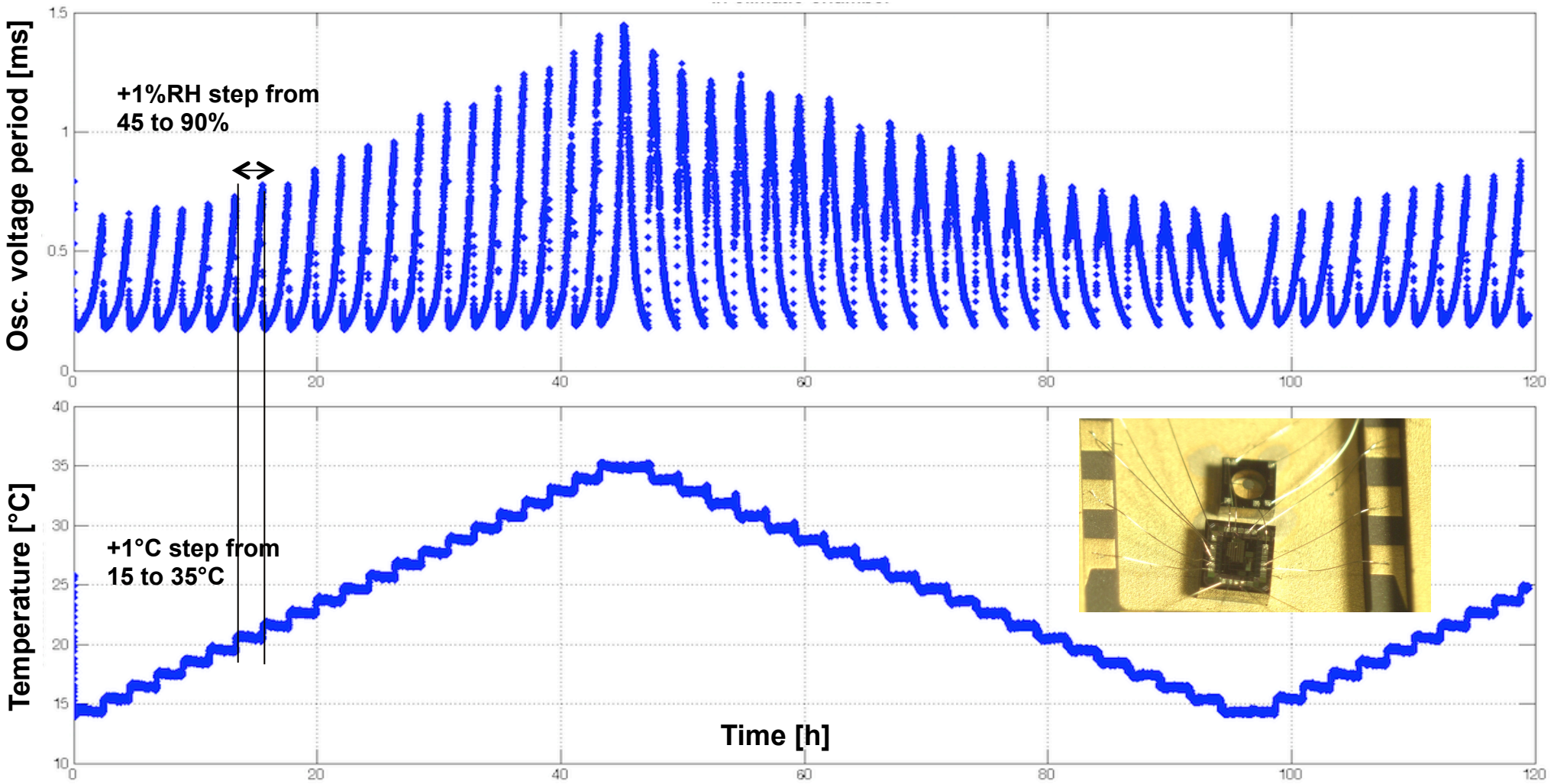
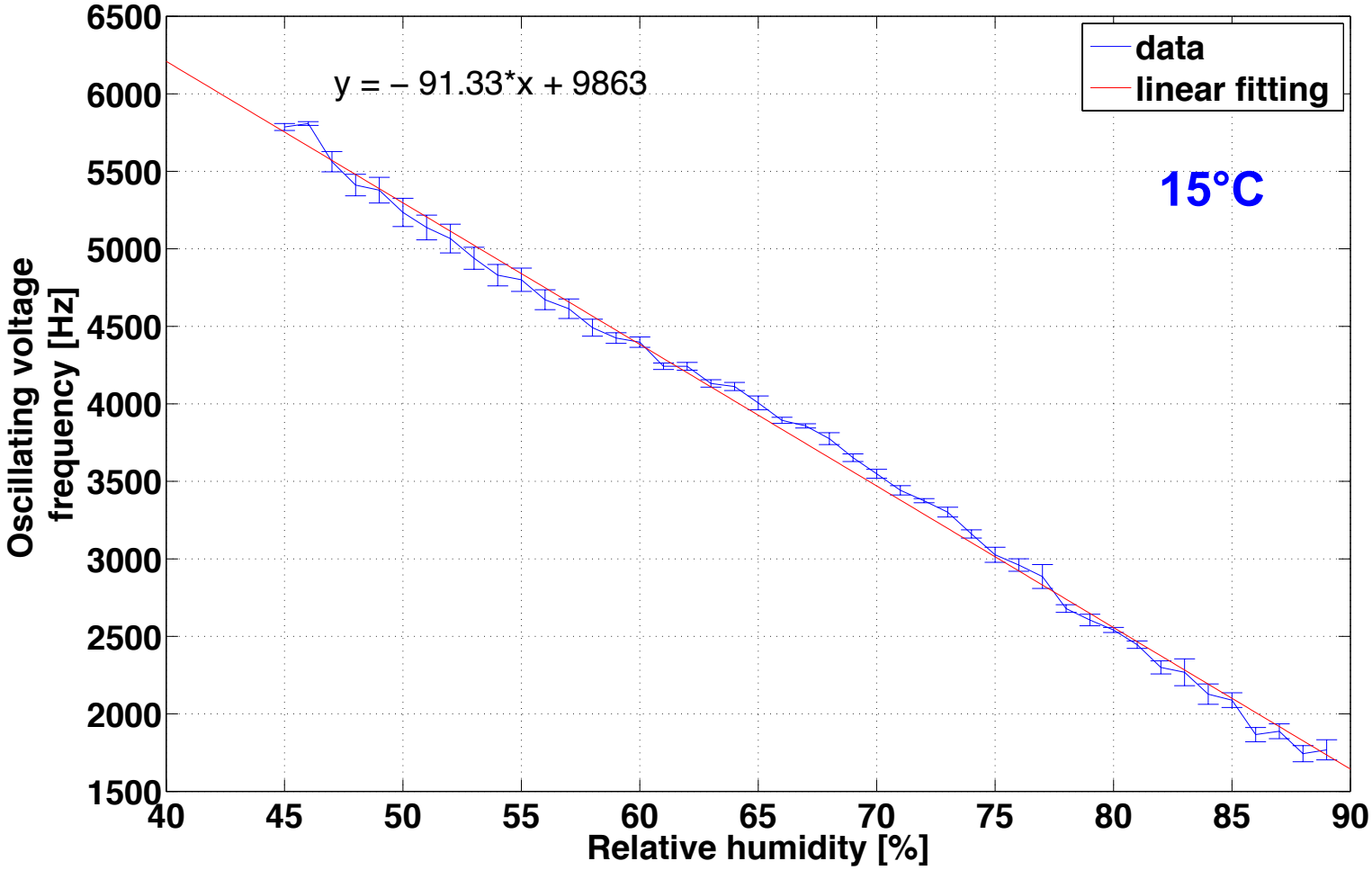


- ≈10x oscillating period increasing
- very small steps: ~continuous variation as weather

Climatic chamber experience results



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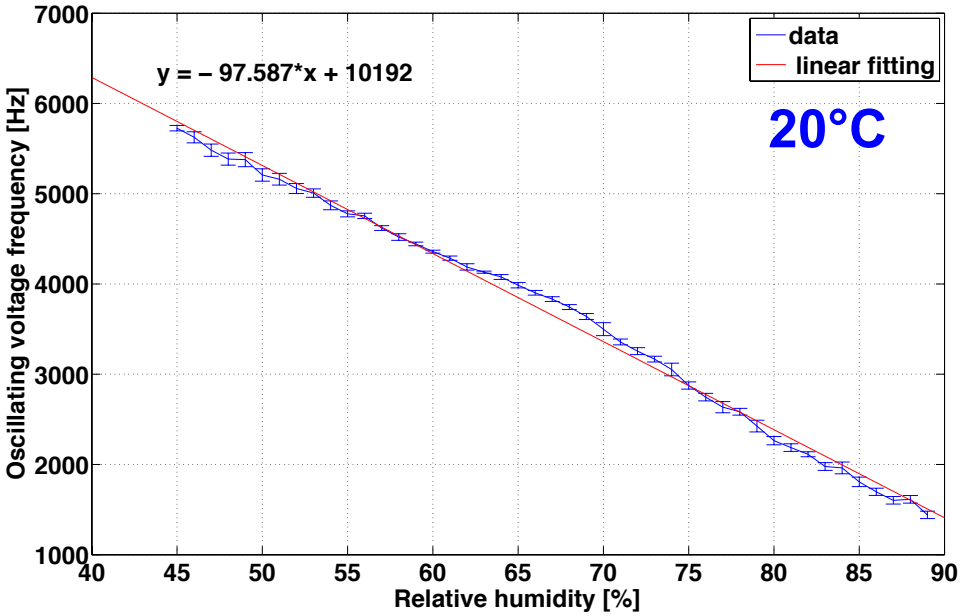
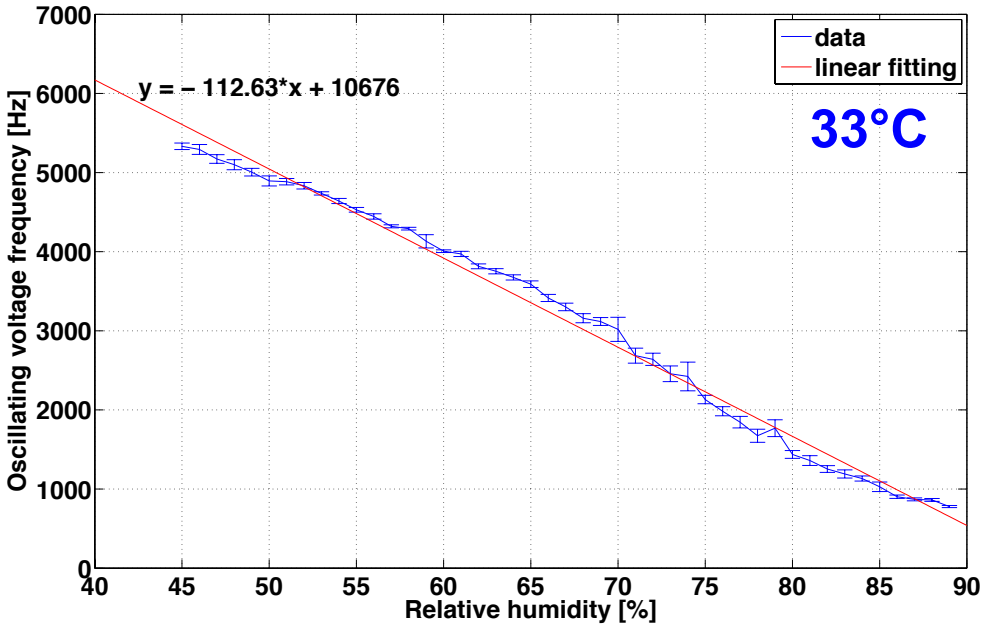
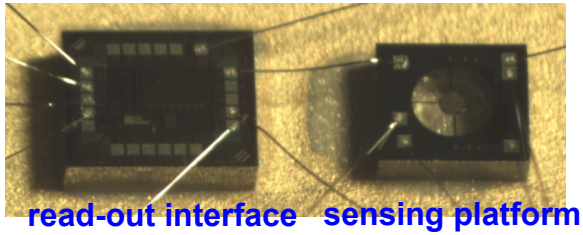




Properties summary

- Simple post-process functionalization with Al_2O_3 coating
- Sensitivity uncoated/coated: 80ppm/%RH vs 2.5%/%RH
- ~2% non linearity error
- ± 2-3%RH accuracy
- Very fast: 0.5 s
- Low power: 200 µW



read-out interface sensing platform

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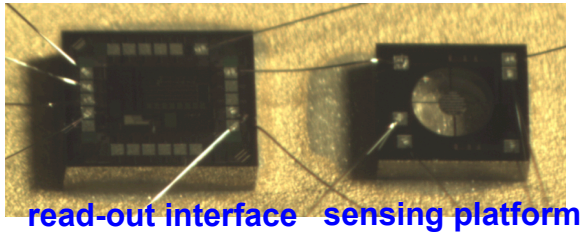
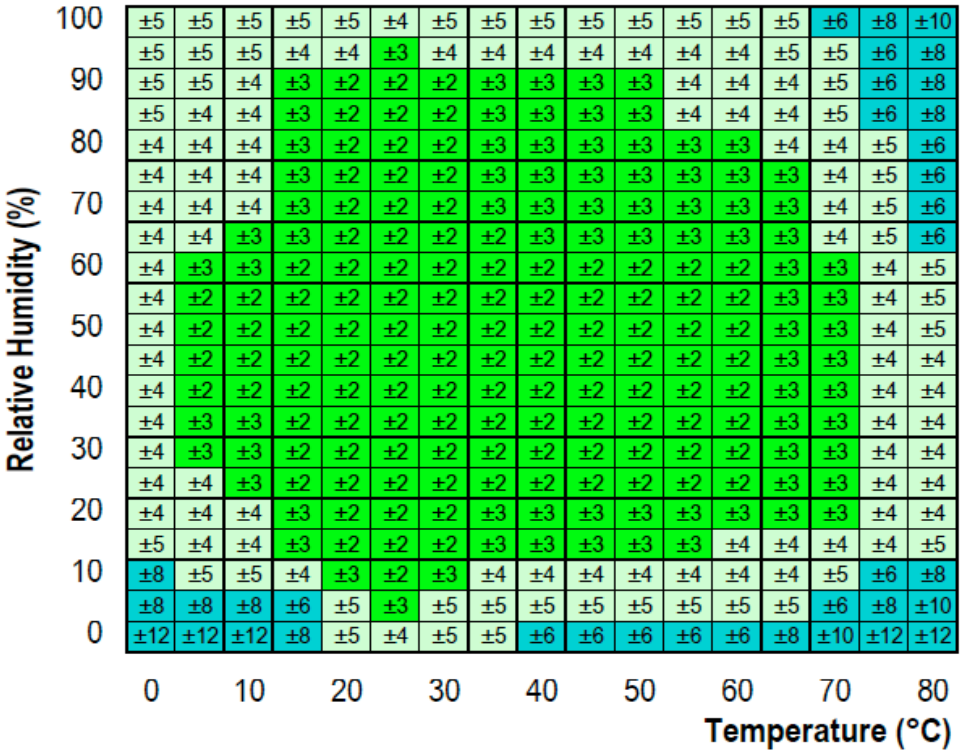


read-out interface sensing platform

%RH accuracy for %RH Sensirion
±2%RH (up to ± 12%RH according ambience)

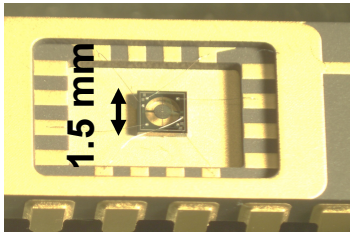


- However, more tests have to be done

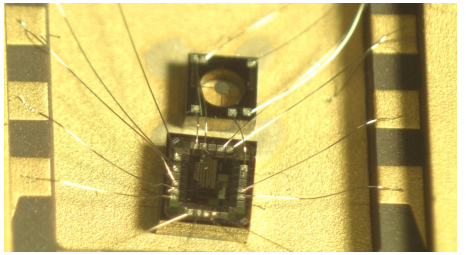
to extend T, %RH range and to determine the best ageing conditions

Conclusions

1. **Functionalized microhotplates with readout interface for “point-of-care” humidity sensing have been demonstrated**



Microhotplate



Circuit + microhotplate

2. **CMOS-SOI-MEMS technology is very promising to meet the *More-than-Moore* roadmap for environment gas sensing**

3. **Real experimental conditions are new for university labs and so teach a lot!**

Acknowledgements

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  - G. Pollissard-Quatremère[1], N. Couniot[1], P. Gérard[1], Z. Ali[2], F. Udrea[2,3], L. A. Francis[1] and D. Flandre[1]

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    [2]Cambridge CMOS Sensors, Cambridge, United Kingdom

    [3]Department of Engineering, Electrical Engineering Division, University of Cambridge, Cambridge, United Kingdom
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