

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

COST Action TD1105

INTERNATIONAL WG1-WG4 MEETING on

New Sensing Technologies and Modelling for Air-Pollution Monitoring

Institute for Environment and Development - IDAD

Aveiro, Portugal, 14 - 15 October 2014

Action Start date: 01/07/2012 - Action End date: 30/06/2016 - Year 3: 2014-15 (*Ongoing Action*)

A Silicon-on-Insulator Platform Functionalized By Atomic Layer Deposition for Humidity Sensing

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Invited Meeting Participant

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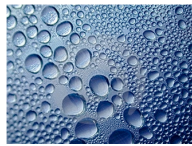
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de Louvain



More-than-Moore sensors for ... combustion process monitoring

More-than-Moore sensors for combustion process monitoring

- FP7 SOI-HITS: System-in-Package (SiP) demonstrator for domestic boiler monitoring
- Methane combustion process :
$$\text{CH}_4 + \text{Air} \rightarrow \text{CO}_2 + \text{H}_2\text{O} + \text{CO} + \text{NO}_x$$
- Measurements of CO_2 , O_2 , CO , %RH and temperature at about 20-30 cm above the burner, i.e. up to 225°C



Humidity



Hot

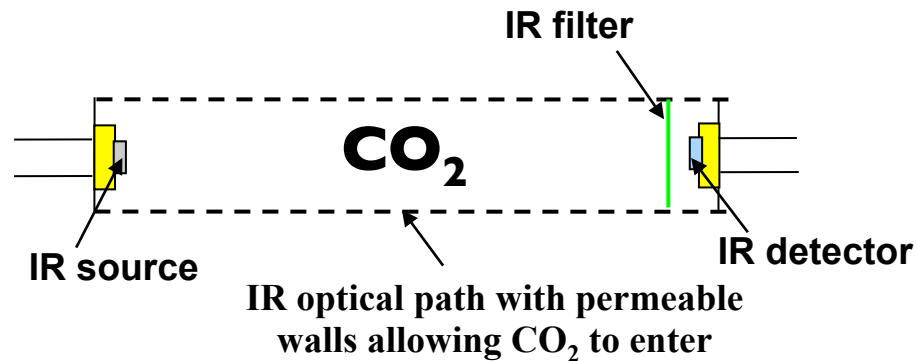


Best boiler tuning

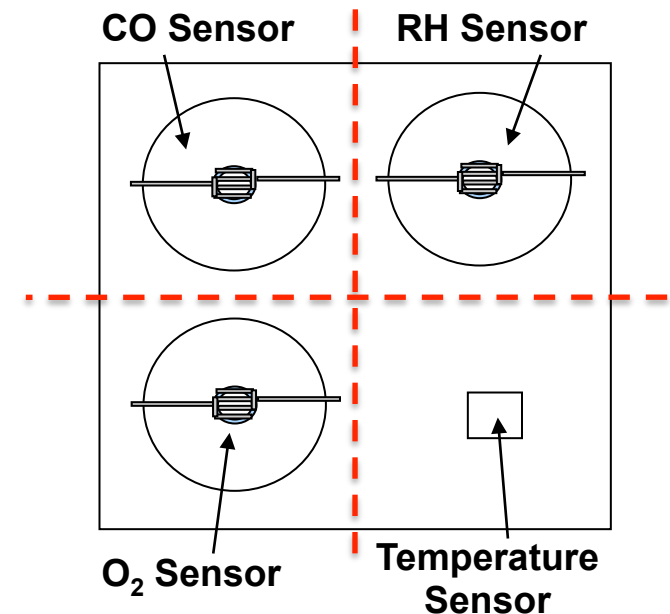


Combustion process monitoring

- **FP7 SOI-HITS: System-in-Package (SiP) demonstrator for domestic boiler monitoring**



Nondispersive infrared sensor



Multisensor platform

Miniaturized platforms, why?

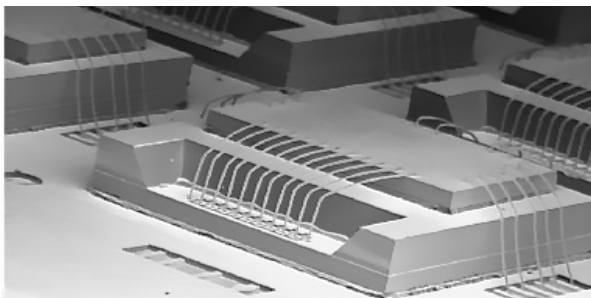
2 mains roads

Constant progress in microelectronic:

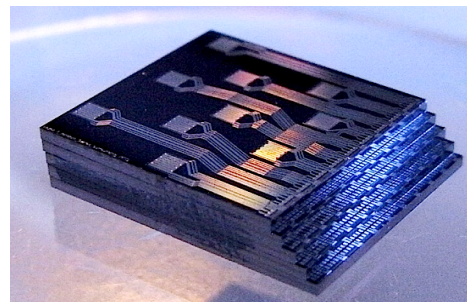
- Moore's Law: only 10% of the chip area
- Remaining 90% is the *More-than-Moore* concerns
 - adding value to computing and memory devices
 - sensors miniaturization, RF link, ...



Hybrid integration System in a Package (SiP)

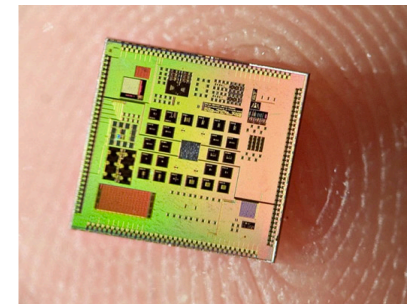


STMicroelectronics (2008)



EPFL (2010)

Co-integration System on a Chip (SoC)



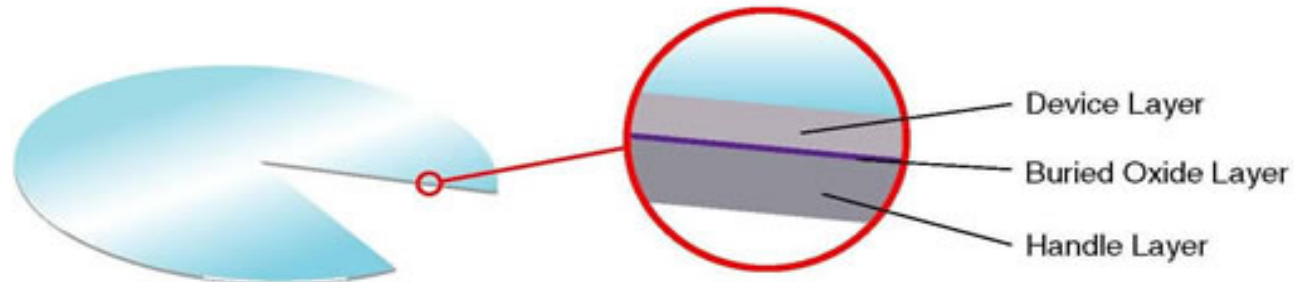
T. Constandinou (2005)

More-than-Moore technologies

Advantages of SOI for high temperature membrane platform

- Great SOI CMOS performance: low power, no latch-up, low crosstalk, low substrate capacitances, good high-temperature performance, RF performance, rad-hard resistant, ...
- Membrane fabrication: excellent etch stop for bulk micromachined membrane
- On-membrane sensing: excellent thermal insulation from substrate for thermal layer activation (low power), small thermal inertia (fast heating/cooling)

Silicon On Insulator Wafers (SOI)



More-than-Moore technologies

Where do we (post-)process and characterize?

Supporting facilities at UCL, Belgium:

Winfab – UCL clean room fabrication facility (CMOS – MEMS)

**Welcome – UCL characterization and measurement platform
(DC – 110GHz, 3K-300°C, climatic chamber, etc...)**



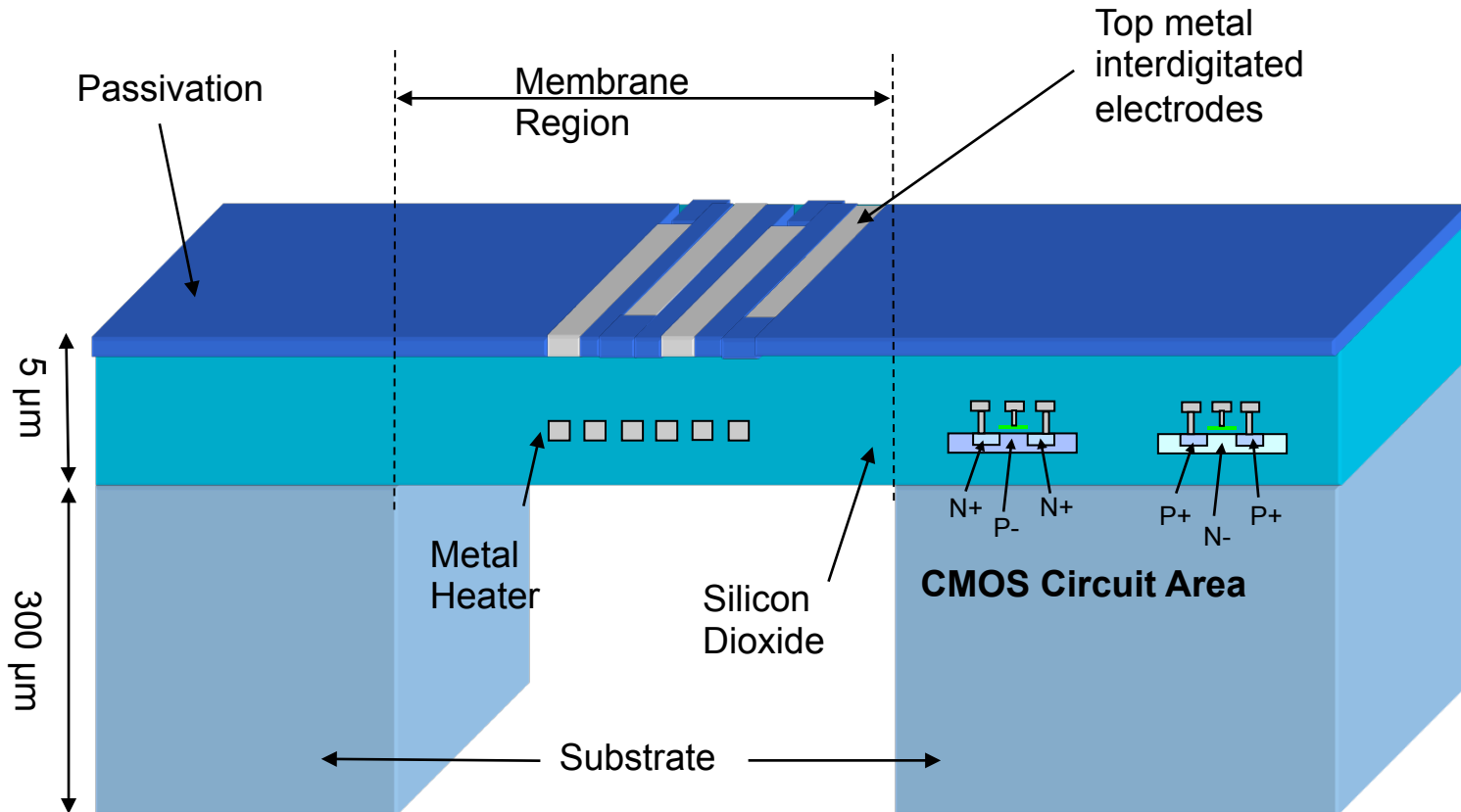


SOI sensor platform description

The Sensor Platform

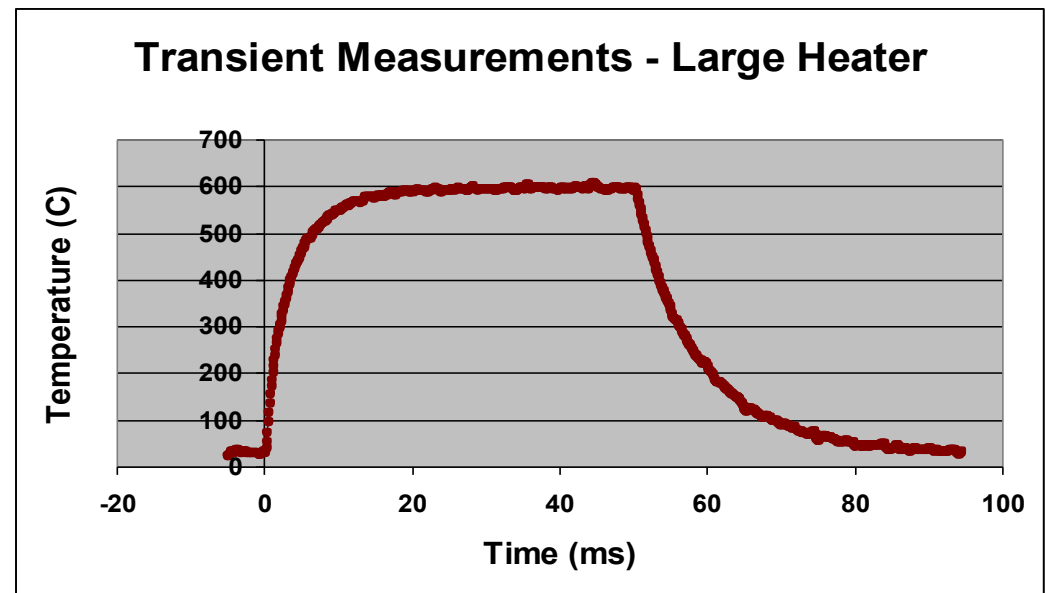
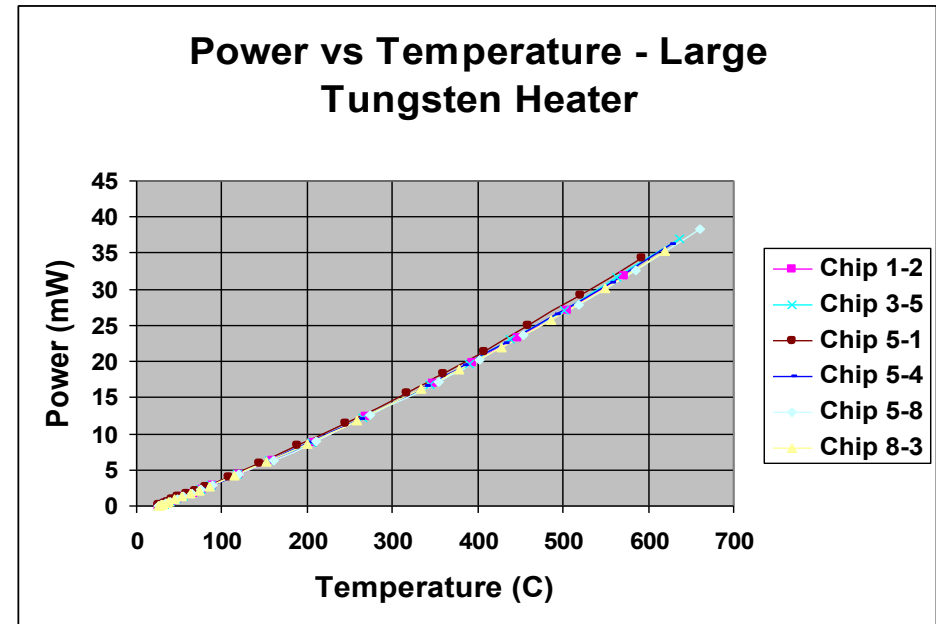
- **The Sensor Platform is:**
 - **A Micro-hotplate device**
 - **Based on SOI-CMOS process**
 - **All advantages of CMOS – Low Fab Cost, good reproducibility**
 - **Integrated Circuits can operate at high temperatures**
 - **Thin Si layer for additional structures and devices.**
 - **Tungsten Metallization (to form heater)**
 - **CMOS Compatible**
 - **Stable at High temperatures**
 - **DRIE Post Processing**
 - **Vertical Sidewalls – less chip area used**

Micro-Hotplate Sensor Platform



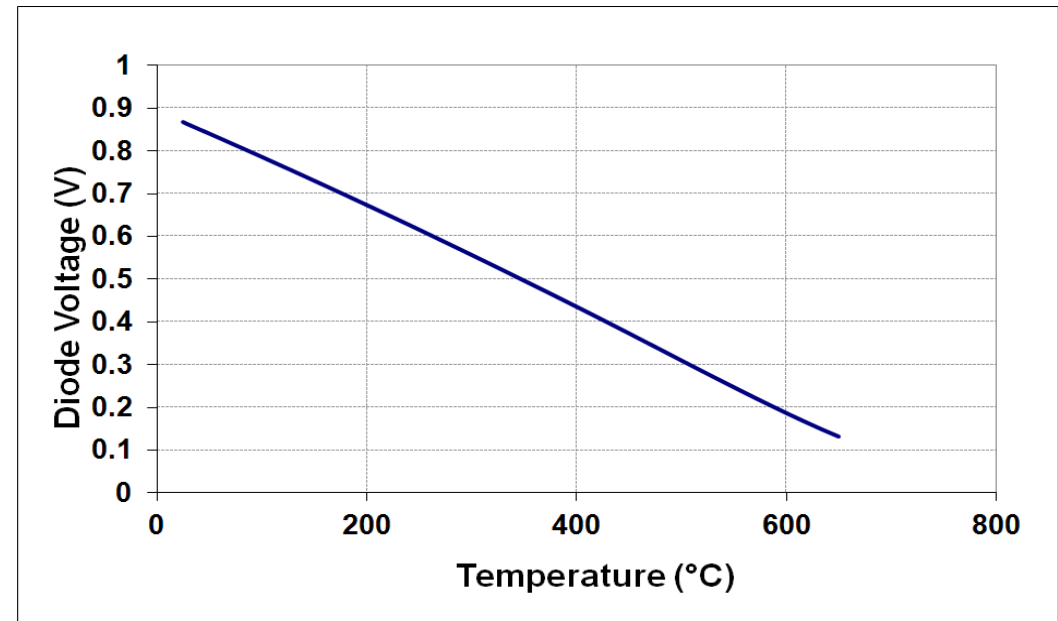
Micro-Hotplate Sensor Platform

- Electrothermal properties:
 - Reproducible across wafer, uniform, very good insulation, low thermal mass
 - 35 mW for 600°C,
 - Thermal transient time: rise time 10 ms, fall time 20 ms



Micro-Hotplate Sensor Platform

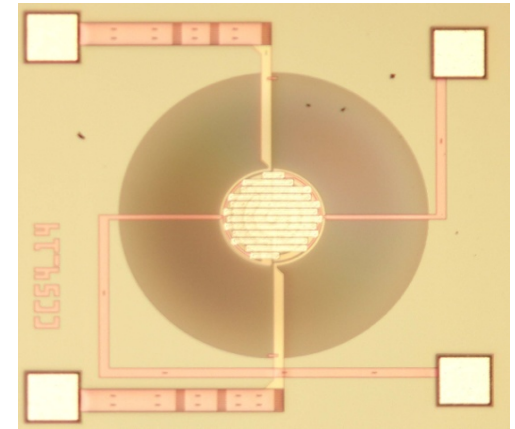
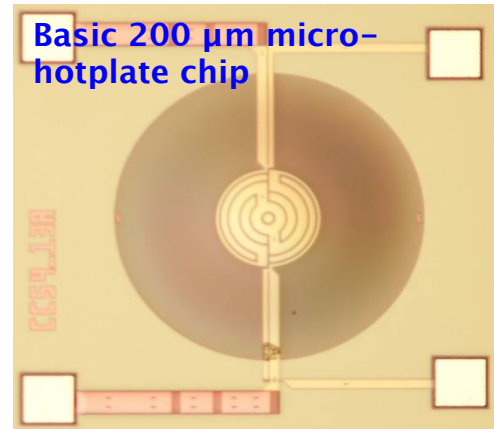
- Electrothermal properties:
 - Reproducible across wafer, uniform, very good insulation, low thermal mass
 - 35 mW for 600°C,
 - Thermal transient time: rise time 10 ms, fall time 20 ms
 - Long term testing: 2% resistance variation for 10.000 h/10 Hz/400°C,
 - Thermodiode: ~1 mV/K up to 600°C



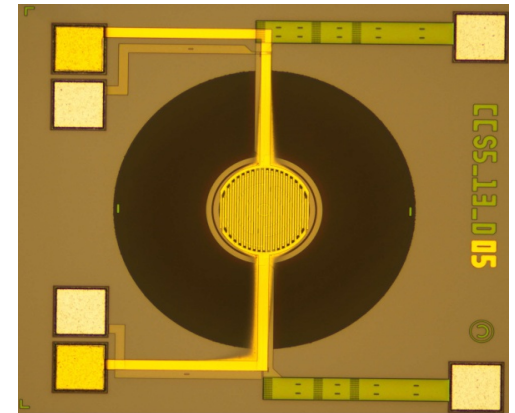
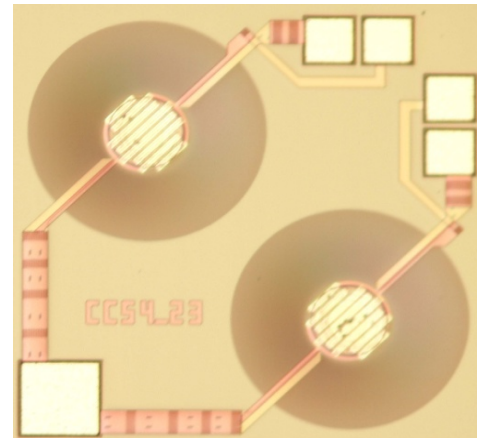
Diode Forward Biased at 65 μ A

Micro-Hotplate Sensor Platform

- Gas Sensing :
 - Calorimetric
 - Impedimetric: IDE
 - Differential meas.
 - Co-integrated IC possible



UNIVERSITY OF CAMBRIDGE
CAMBRIDGE CMOS SENSORS

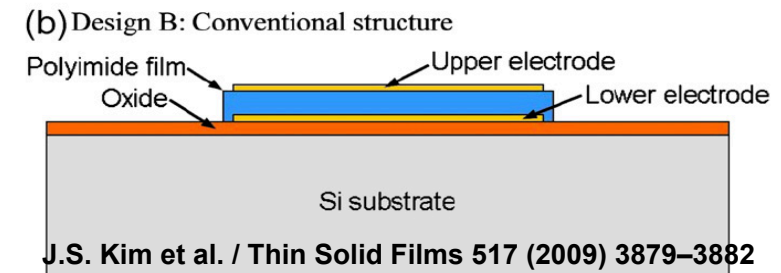
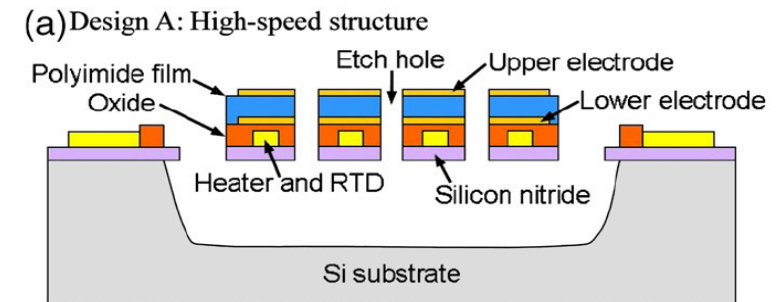




Water vapour sensing

Miniaturised humidity sensors

- Operating principles :
 - resistive
 - thermal conductivity
 - capacitive
- Technological trends:
 - widespread use of polyimide (PI) – easy to process and linear response
 - thin and porous (ceramic) materials – lower time response
- Main parameters:
 - sensibility, humidity & T range
 - response time and stability
 - hysteresis (drift between hum. rise/fall)



Commercially available sensors

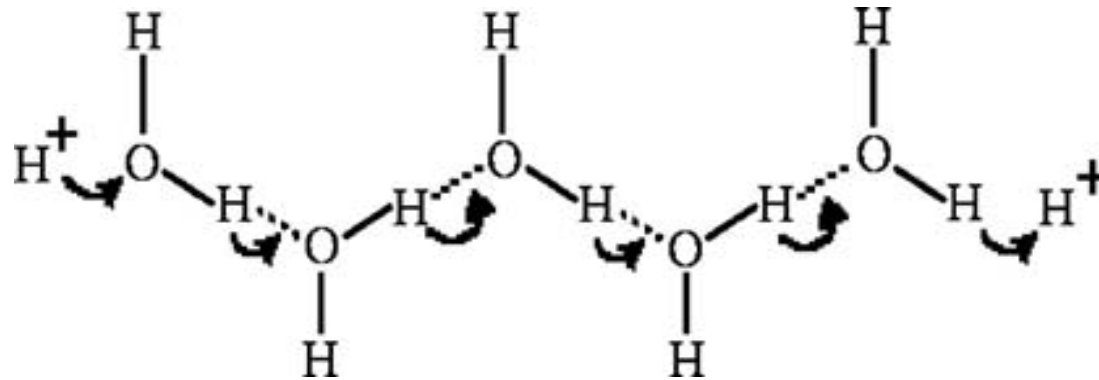


Honeywell HCH-1000 Series
Typ. 5 € piece
-40°C to 120°C
Response time 15 s
Polyimide



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

Surface adsorbed water on metal oxides



***Grotthuss* mechanism with ceramics like Al_2O_3 (hydroxyl-terminated) for physisorbed layers**

Protons hopping through hydrogen bonding

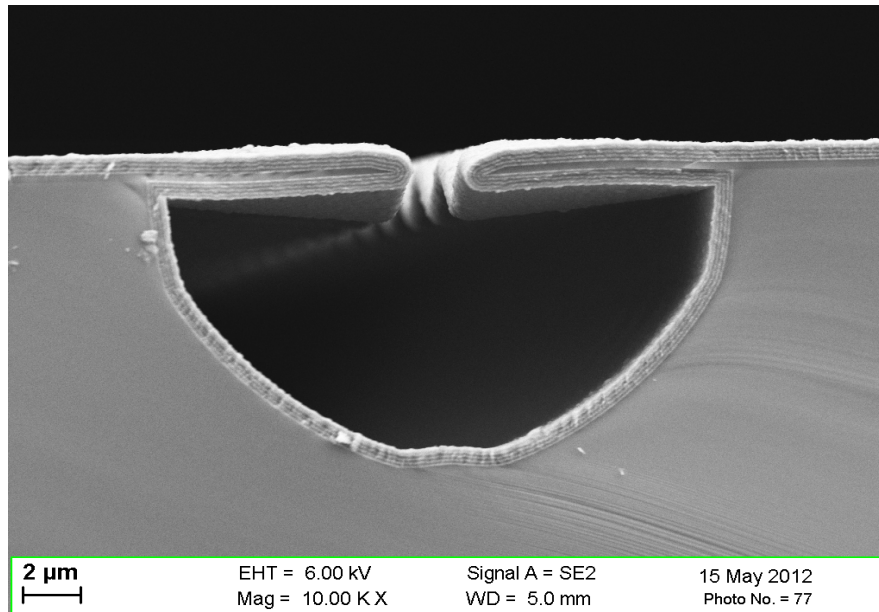
→ conductivity increase

Addition of water molecules, free to orient themselves

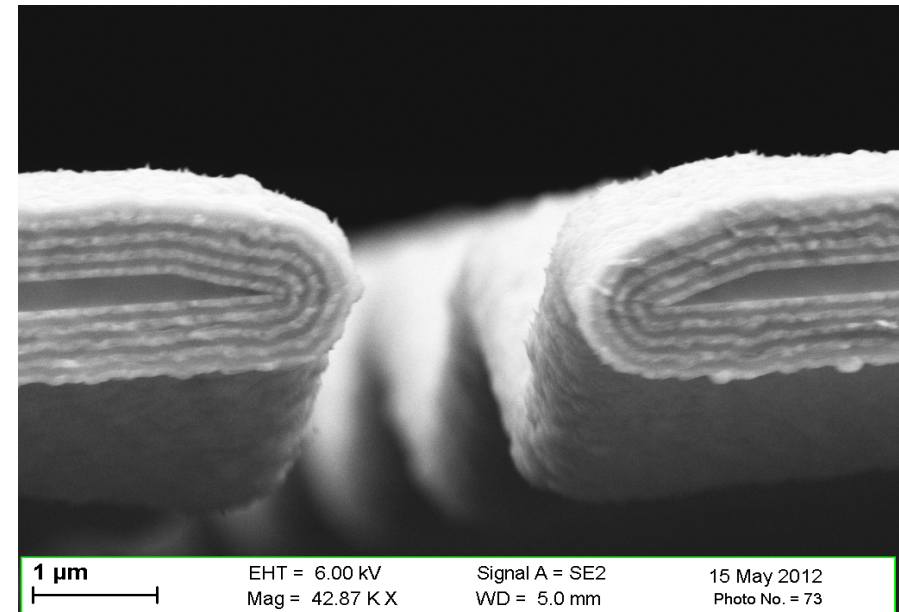
→ dielectric constant increase

ALD- Al_2O_3 functionalized microhotplates

- Atomic Layer Deposition (ALD) @ UCL:
 - highly uniform, conformal inorganic solid thin films
 - allows the deposition of monolayers at room or higher temperatures
 - principle: exposing the surface to vapors of two or more chemical reactants



Stack $\text{Al}_2\text{O}_3/\text{TiO}_2$
Highly conformal and controlled

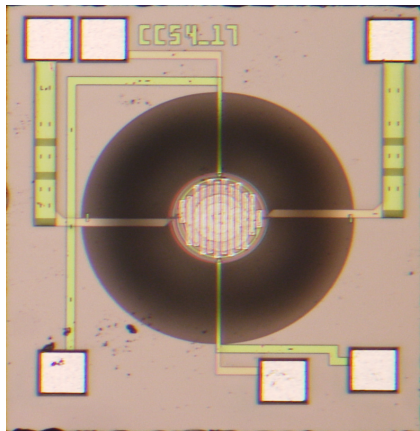


O. Poncelet, UCL 2012

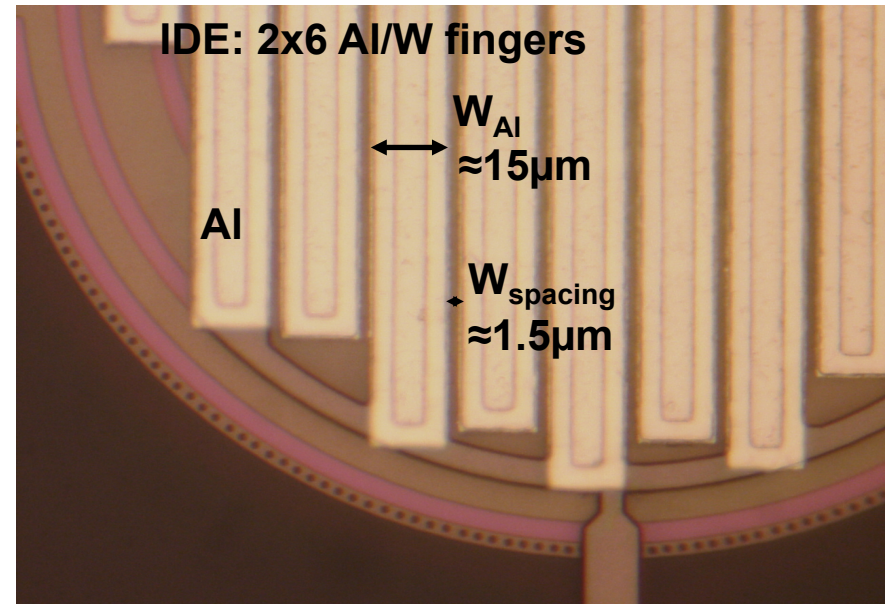
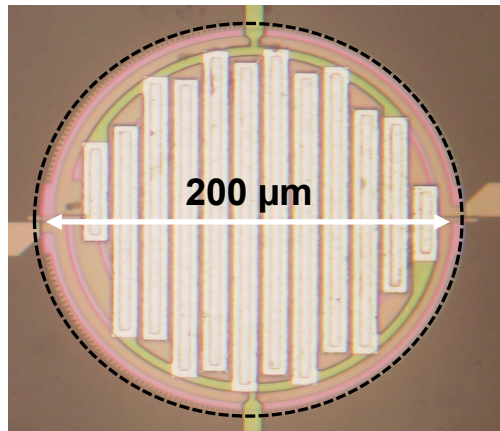
ALD- Al_2O_3 functionalized microhotplates

- Different designs

- generic platform among the project partners
- ALD-coated Al_2O_3 micro-hotplates for water vapor sensing,
- local heating for fast recovery after condensation, anti-drift methods and cleaning



ALD Al_2O_3 25 nm, thermal, 150°C,
precursors: H_2O and TMA





Highlights

Water vapor measurements set-up

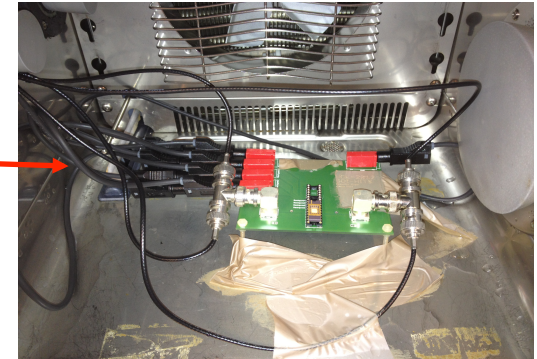
- Impedimetric measurements under variable %RH and T, without circuit interface



HP4284A LCR meter



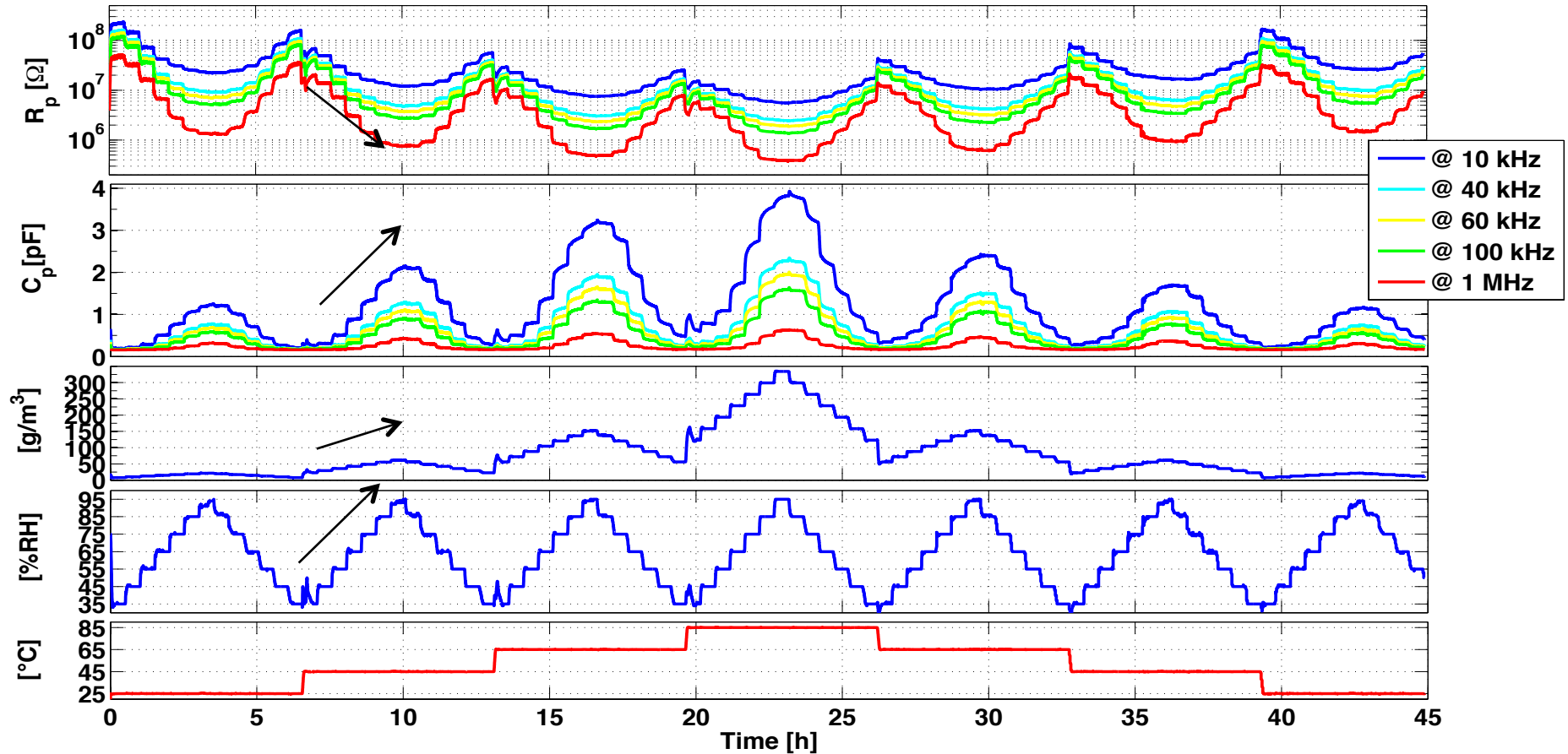
ESPEC SH-261:
• 25 to 85°C,
• 35% to 95% RH



Inside the climatic chamber:
• Micro-hotplate on a DIL16

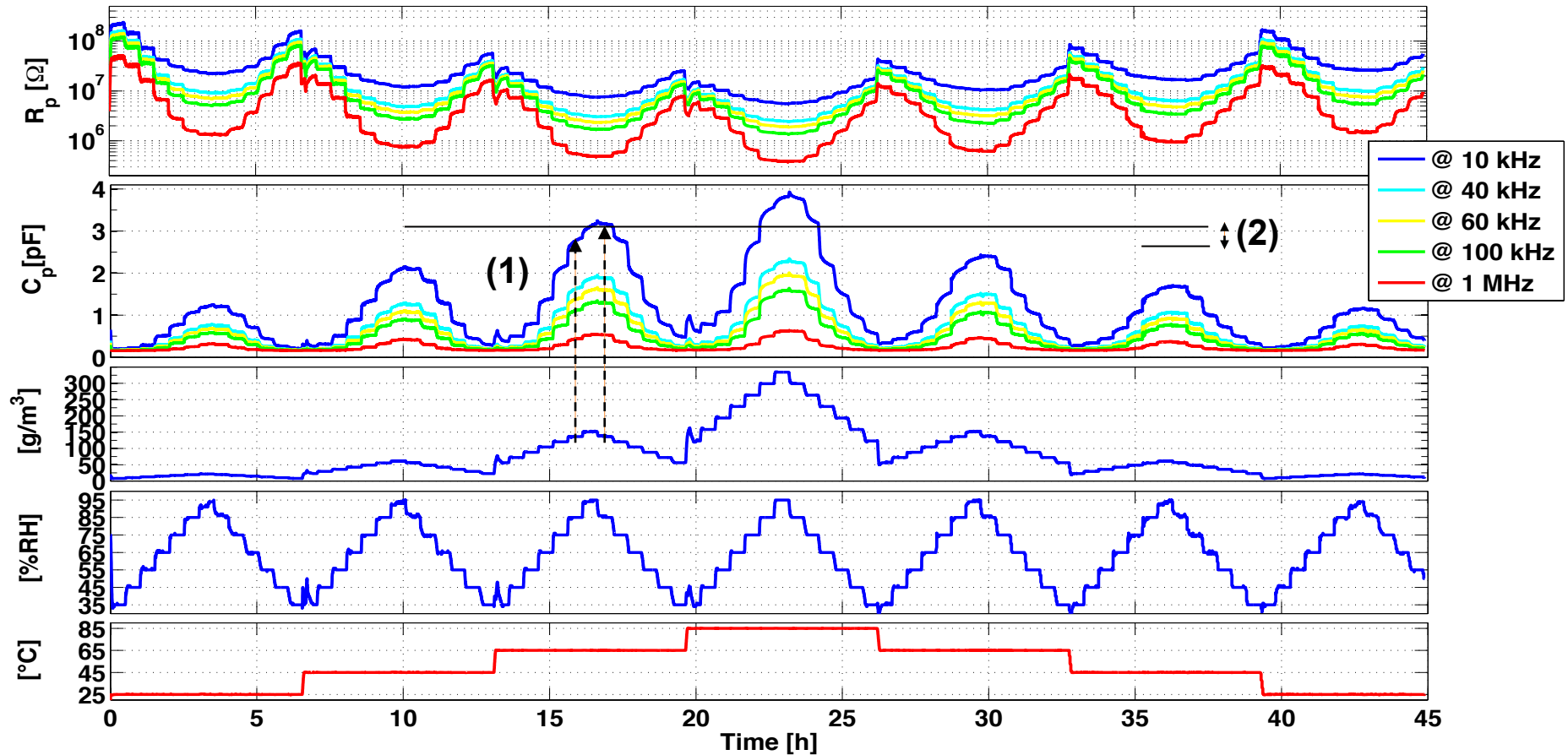
Climatic chamber measurement results

- Al/Al₂O₃ IDE impedimetric measurements results,
- $\approx 10\times R_p$ decreasing, $10\times C_p$ increasing due to water vapor adsorption,
- ALD Al₂O₃ decreases the long-term drift compared native Al₂O₃



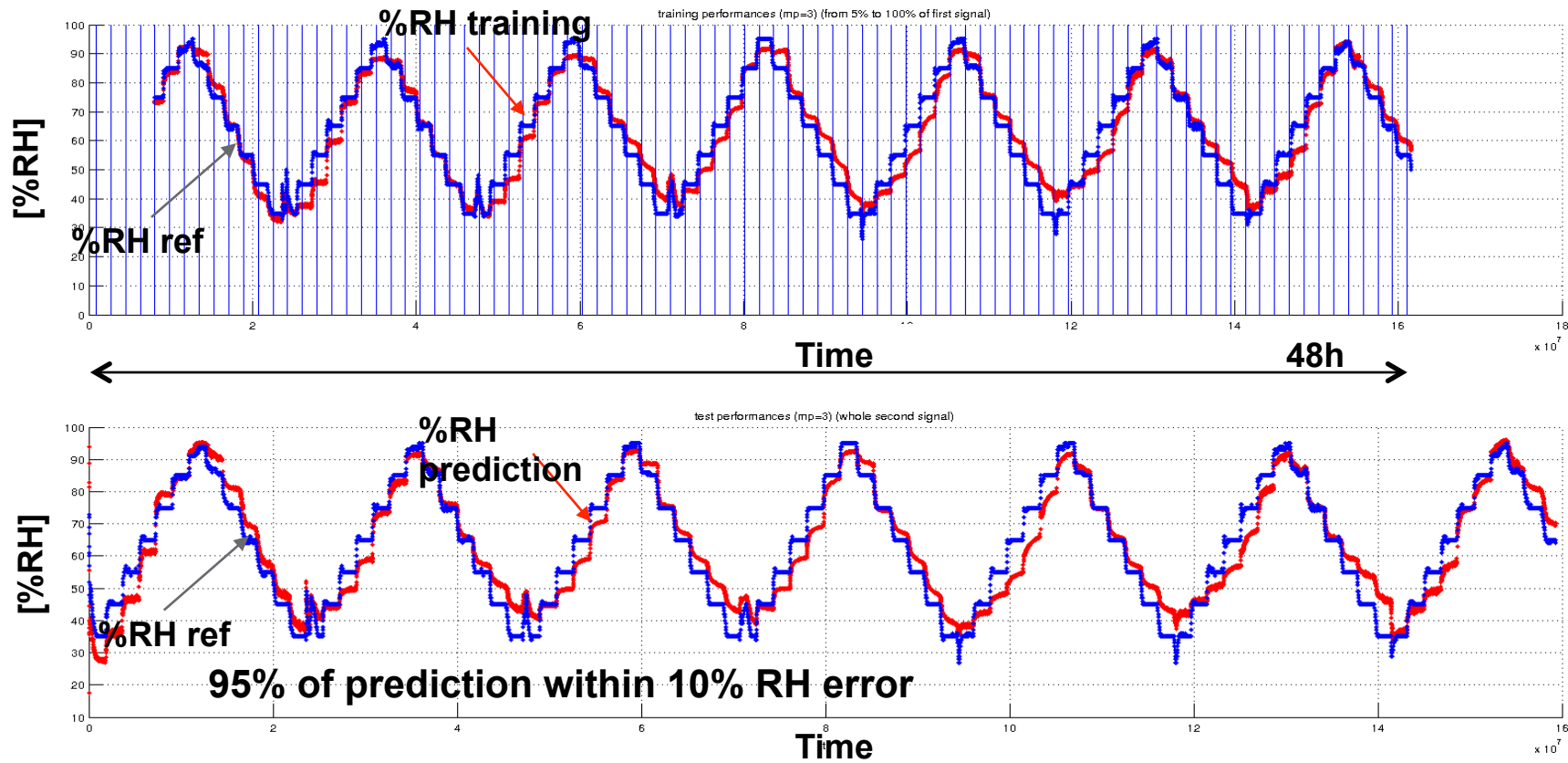
Hysteresis and long-term drift

- Al/Al₂O₃ IDE impedimetric measurements results,
- important hysteresis between crescendo/decrescendo %RH at same T step (1)
- important long-term drift for 2 successive T steps (2)



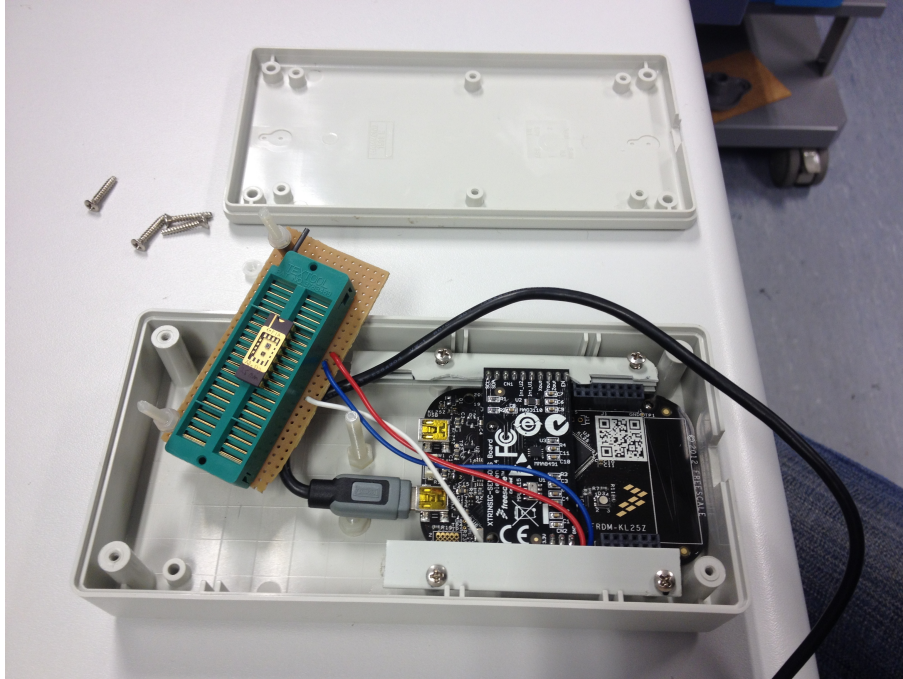
Drift-hysteresis corrections

- correction of Al/Al₂O₃ IDE impedimetric measurements results by machine learning
- local heating: for ex. +10°C wrt T_{ambient} => correspond to a ≈40–50% local %RH decreasing
- Au IDE more robust at HT
- sensor ageing



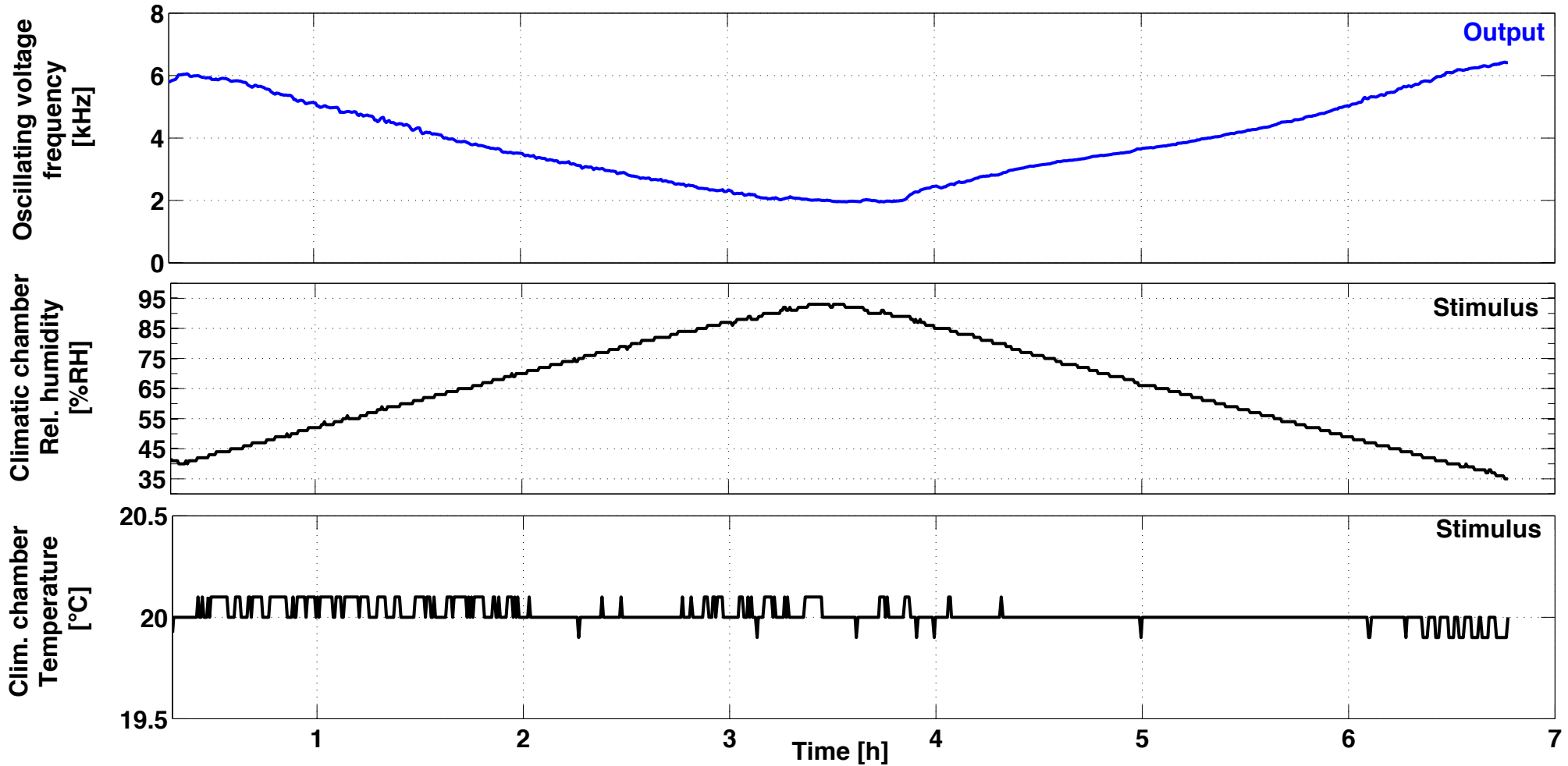
CMOS-SOI platform for %RH monitoring

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



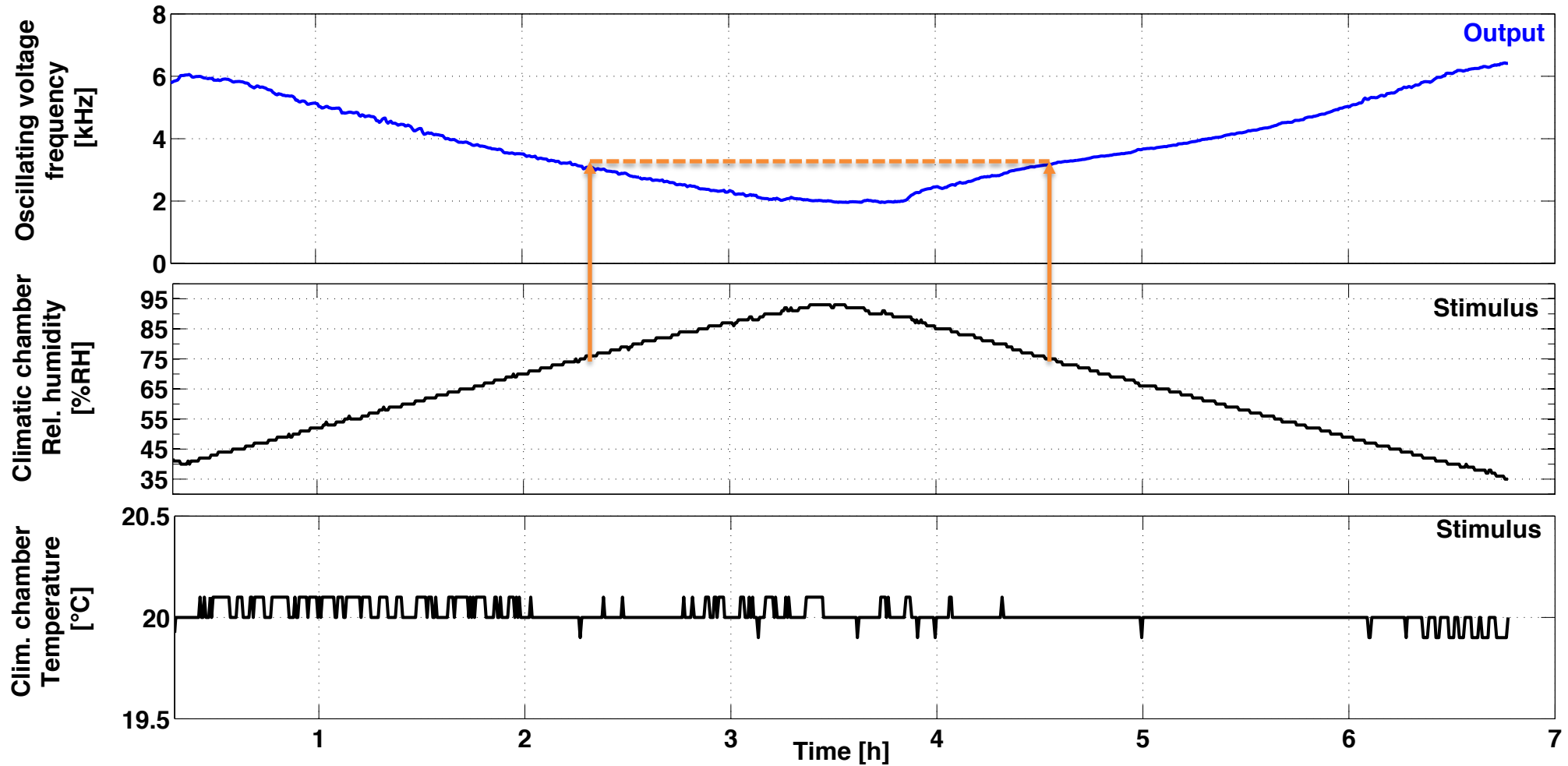
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CMOS-SOI platform for %RH monitoring

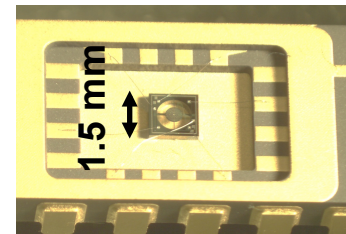
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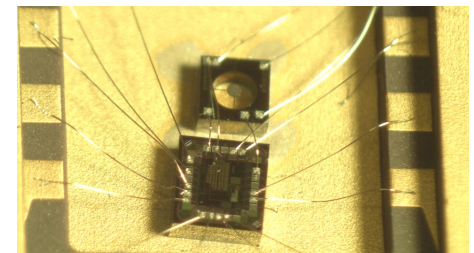
Summary

1. SOI substrates are of clear interest for MEMS devices and sensors
→ **SOI-MEMS**
2. CMOS on SOI is great and demonstrated benefits, as low power and harsh environments operation
→ **CMOS-SOI**
3. An excellent combination to meet the *More-than-Moore* roadmap for harsh environment gas sensing
→ **CMOS-SOI-MEMS**

**Multifunctional suspended microhotplates
With SOI readout interface
For “point-of-care” gas analysis**



Microhotplate



**Circuit +
microhotplate**

Acknowledgements

- **Many thanks to co-authors**

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